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DIPLOMOVÁ PRÁCE
MASTER'S THESIS

AUTOR PRÁCE BC. PETR KNOPP
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MULTIMEDIÁLNÍ SÍTĚ V AUTOMOBILECH
MULTIMEDIA NETWORKS IN CARS

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BRNO 2009

ZDE VLOŽIT LIST ZADÁNÍ

Z důvodu správného číslování stránek

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ABSTRAKT
Moderní elektronika se stává nezbytnou součástí dnešních automobilů. Dynamicky se rozvíjející informační a telematické služby nacházejí široké uplatnění v automobilovém prostředí. Moderní aplikace vyžadují přenos velkého množství dat, což jim zajišťují dnešní komunikační protokoly. Cílem mé diplomové práce je analýza a návrh implementace mutlimediálních sítí do automobilů. Jednotlivé návhy jsou chrakerizovány a srovnány podle požadavků, kterým jsou v automobilovém prostředí vystaveny. Navržené topologie využívají nejen dnes používané technologie, ale jsou zde i návrhy, které nebyly dosud v automobilovém prostředí použity. Jednotlivé návrhy jsou srovnány a vyhodnoceny z pohledu automobilového výrobce.

KLÍČOVÁ SLOVA
multimediální síť, automobilový, CAN, MOST, IDB1394, APIX, optické vlákno

ABSTRACT
Automotive manufacturers face interesting challenges as electronic devices are becoming essential in modern vehicles. One of the most rapidly growing domains is infotainment and telematics, where applications require a large amount of data to be transmitted on-board and also exchanged with the external world. This thesis is intended to analyze possible implementations of multimedia networks in vehicles, in relation to various aspects and features in this area. Based on various requirements different multimedia networks are proposed and studied, making a comparison between them with regards to a number of criteria. A broad approach during the investigation of the multimedia protocols is chosen in order to enlarge the area of used technology. The comparison gives an insight into the particular proposed solutions from the automotive industry's point of view. Based on the comparison of the proposals a suitable multimedia network can be chosen.

KEYWORDS
multimedia networks, automotive, performance requirements, vehicle, CAN, MOST, IDB1394, APIX, optical fiber

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PROHLÁŠENÍ

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V Brně dne ....

(podpis autora)

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INTRODUCTION

The automotive industry reached an important stage of its development process. Automotive companies are generally becoming more open to introducing new technologies into their products. Thus, plenty of new technologies are developed to fulfill the increasing requirements for heterogeneous services on-board and to provide sophisticated vehicles equipped by various modern technologies. Multimedia networks in automotive environment, which is the focus of this project, belongs to one of the significant and rapidly improving technologies. The multimedia networks in the car industry is currently undergoing the dynamic changes. My work will considerably benefit from the experiences gained during the development and implementation process of multimedia technologies in the car industry. The newly introduced technologies can bring to the car manufacturer a great deal of benefits for the competitive automotive industry. This project is based on [1].

Pursuing these lines of thoughts, my project is intended for the development process and implementation of multimedia networks into the automotive environment. In the first part of the project the current multimedia communication technologies and protocols used in the automotive domain are deeply studied. The second phase is closely related to the performance requirements of the current infotainment and telematics systems. An important aspects that may affect the design and choice of multimedia communication networks are discussed and the relations between them are explained. Finally, the third phase, analysis how particular multimedia protocols could be integrated in the electronics architectures of the car and which network topologies meets all of the requirements best. Solutions satisfying different aspects are proposed and the trade-offs between various alternatives are explained. In another words, by combining the results from the first and the second phase, the third phase is accomplished by the suggestion of different networks topologies and their further specifications. This thesis proposes different multimedia networks topologies, which constitutes an important step towards establishing the needs of multimedia automotive networks in the automotive industry.

1 INFOTAINMENT SYSTEMS AND RELATED PROJECTS

1.1 Background - Automotive Embedded Systems

Automotive systems can be defined as combination of mechanical, electronic, control and software components belonging to the wider area of mechatronics [2]. Embedded systems are systems, where the computer is a part of a larger system performing its requirements. Embedded systems are widely implemented in today's automotive industry and are significantly changing the properties of the device they are embedded into [2]. Automotive embedded systems provides working environments for automotive applications. Generally the automotive applications are divided into different groups from different points of view (e.g. front seat, back seat and under the hood applications). In this project Iam focused on the automotive multimedia systems, where the multimedia applications are represented by the Telematics and Infotainment systems.

1.2 Telematic and Infotainment Systems

This section gives an overview of common telematics and infotainment systems which can be integrated in the vehicle, and as consequence have impact on the in-vehicle networks.

1.2.1 Safety and Security

Adaptive Cruise Control: A forward-looking radar usually placed behind the grill together with digital signal procesor detects the relative speed and the distance of other vehicles. If the distance to the vehicle ahead is too small, the driver will be warned. Furthermore the speed is adjusted to the lead vehicle by intervening in the engine or break management.

Lane Departure Warning System: In a lane departure warning system a front camera, which can be located behind the windshield, tracks the visible lane markings. Those images are sent to a CPU running an image recognition software, together with other data such as vehicle speed or steering angle. In case of a lane departure the driver is warned by either an optical or acoustic signal, a vibration of the steering wheel or the seat, or a combination of these.

Cameras: Cameras and streaming video will be the main drivers for the need of a high-speed backbone. Such cameras can be located anywhere around the car. Examples could be a front-camera for detecting objects or people in front of the car as well as for a lane departure warning system, side cameras which make overtaking of other vehicles and integrating into another lane much easier and finally a backup camera.

1.2.2 Remote Vehicle Diagnostics

Remote vehicle diagnostics provides high potential of reducing costs. Some important applications are given below.

Breakdown Assistance: All new vehicles in Europe must be equipped with an automatic emergency call system called eCall by the year 2009 [3]. The eCall system will forward the exact location of the vehicle in the case of a crash to an emergency service using the location-enhanced single European Emergency number (E-112) [3]. This call can be initiated automatically or manually. Therefore the vehicles have to be equipped with a GPS receiver and at least a GSM link.

Warranty Analysis: Error codes can be forwarded wirelessly to identify warranty trends. Furthermore the fault identification time as well as the "no fault found" components can be reduced. The latter is the case when the driver observes an unusual behavior of the vehicle, but it can not be reproduced again at a service point. Costs can be reduced, as the production of potentially faulty vehicles will not be continued. The transmission of vehicle running data can help the vehicle manufacturer to improve future vehicle design. As a GPS receiver and a GSM transmitter will be compulsory due to the eCall system, there will be no need for additional hardware in the vehicle.

Remote Software Download: The possibility to automatically download patches to fix ECU based errors brings the advantage of cost savings on recalls. Apparently the security question has not been answered satisfactorily at the moment.

1.2.3 In-Vehicle Telephony Systems

An important technology for this purpose is Bluetooth. As the major European car manufacturers already provide Bluetooth at least as an upgrade option, it is just a question of time, when it will be implemented into every vehicle. The Bluetooth link can be used to realize hands free telephony as well as to enable the mobile's

GSM transmitter to send telematics data. The problem is still that it results in prohibitive cost and that not all mobile phones are supported due to the lack of profiles. However [4] claims that as soon as the number of Bluetooth-enabled phones will exceeds 50 % the cost factor can be ignored. The next approach is to have a fully integrated GSM phone as a module in the network and to use the HMI and audio system to substantiate the GSM functions. Finally an interface between GSM phone and automotive network can be used to send an audio (data) signal to the automotive network and to charge the mobile unit.

1.2.4 Navigation and Fleet Management

Satellite navigation system (Global Positioning System, henceforth GPS) have become a standardized navigation technology for automotive industry. The navigation unit can be as a standalone device with its own display or an integrated device to the multimedia subnet. The integrated version can be further divided according to the software strategy into distributed or complex navigation units. A distributed navigation devices send over the network only the data necessary to discover its position, where the software part located in the head unit will calculate the position and create the video signal. A complex navigation units on the other hand calculate and create the video navigation signal and send the compressed signal over the network. The Fleet Management systems control the vehicle position and behavior.

1.2.5 Audio Video Systems

Not only for the entertainment but also for navigation, telematics and GSM services are audio and video signals used.

Audio Devices: Audio devices can be implemented as a complex or standalone devices and may consist of the following parts:

- Amplifier - analog amplification of the incoming signal
- Radio Tuner - supporting an analog or digital broadcasting with various additional functions e.g. RDS (Radio Data System)
- CD player - including MP3

Video Devices: Video devices are represented by a DVD player (DVB receiver) with connected entertainment display. The video switch is engaged as a switch for the video signals coming from different devices (e.g., a navigation unit or front-camera).

1.2.6 Connectivity

Gateway: The need for cooperation with other networks is satisfied by the gateways, where various items of information from the vehicle can be transferred to the different subnets. This data can be used for e.g. sending a digital odometer data to the company.

Connectivity Box: Represents various interfaces to connect different devices. Further specification of the interfaces is not given, since there is a strong correlation with the suppliers and customers.

1.3 Related Projects

This section gives an overview of current and past projects dealing with in-vehicle multimedia networks. Most projects aim at providing rear-seat entertainment, as this can be seen as the driver for high-speed networks, due in turn, to the trends of the car industry.

1.3.1 Prototype of IDB-1394 Network

The Nissan Corporation has designed a prototype of an in-vehicle network based on IDB-1394 using a ring topology with a bandwidth of 400 Mbit/s which meets the demands for audio and video [5]. The system consists of:

- Main units located in front panel which contains DVD player and DVB-T receiver
- Two rear seat displays
- Audio amplifier

All streams, two MPEG-2 and one PCM audio stream, are transmitted simultaneously. The two MPEG-2 streams of the 30 channels of DVB-T and the DVD video player occupy 32 Mbit/s and 36 Mbit/s respectively. The PCM audio stream needs 10 Mbit/s. In total approximately 30 % of the available bandwidth is used.

The signal of both the DVB-T receiver and the DVD player has to be converted to an MPEG-2 stream. This leads to the problem, that chips for encoding/decoding the MPEG-2 stream are needed which makes the system more expensive and produces delay times of 200 to 300 ms which is not acceptable for real-time rear-view cameras for instance.

Therefore a new IDB-1394 controller, the Fujitsu MB88387, was introduced, which can process the two streams simultaneously. It uses the smartCODEC algorithm which compresses the raw data, YUV or RGB, to one third of its original size. This algorithm, with encoding and decoding times between 2 and 3 ms, meets the required real-time demands. This controller is one possibility to make real-time camera systems feasible and to design rear seat entertainment systems at lower cost.

1.3.2 SCOOT-R

SCOOT-R which is a subset of the European project ROADSENSE, is a framework for software development. It offers a framework for distributing tasks on multi-processing units architecture along with communication and synchronization services. It also includes additional support to verify real-time constraints and to implement fault-tolerant strategies [6, 7]. This reduces the cost as commercial off-the-shelf hardware based on IEEE-1394 can be used. SCOOT-R is implemented as a middleware above the real-time kernel of RTAI Linux.

The main idea is that client-server and emitter-receiver paradigms were developed. The client-server model is used for asynchronous applications whereas emitters and receivers are responsible for synchronous and isochronous traffic with high bandwidth like multimedia streams. Devices acting as emitters are for instance front and back cameras. On the other hand GPS or odometer sensors represent servers.

Fault-tolerance is achieved through partial replication of critical systems, especially the redundancy of servers and emitters. A quality identifier is assigned to each of the servers or emitters respectively. Furthermore this quality identifier is modified dynamically at runtime either explicitly by high-level applications or implicitly by monitoring the application behaviour.

A possible real world application, as presented in [6, 7], is an accurate positioning system of a car in a digital cartography geographical information system in real-time. In this project a GPS module, an odometer module, a GIS module and a front camera are implemented as SCOOT-R servers/emitters and clients/receivers which communicate through the SCOOT-R middleware.

1.3.3 Ad-hoc Network

A problem in today's in-car networking concept is that there are independent networks such as CAN, LIN, Byteflight, d2B, MOST, Flexray, and IEEE-1394b, among others, for the different domains like the power train or body domain. The communication between these domains and their corresponding networks is often done via gateways which acts as an application gateway as there are no common communication layers.

An in-vehicle ad-hoc network would allow dynamic initialization of devices dependent on their built-in location or the car type instead of configuring the devices manually which will be more complex with the number of devices. Also an intelligent power management device (a device that can for instance be sent into sleep mode) causes the network to be dynamic. Furthermore a reconfiguration of the network at runtime may be needed due to the flexible topology of IEEE-1394. A good example for the latter is the consumer convenience port (CCP) of the IDB-1394 network.

In the ad-hoc network proposed in [8] the main communication network is divided into several specialized modules as for instance a telematics module, a powertrain module or a dashboard module. Each module contains a network, optimized for its purpose. The module itself represents a gateway in the main communication network. This architecture allows a more selective and optimized power management. Also one failing node does not wake up the whole system.
To realize this ad-hoc network a new session layer was defined. In this session layer the connection is not described by network and transport layer address, for instance IP address and port number in TCP/IP networks, but by an application and a session address. A lookup service requests the actual node address, node unique numbers and application information of all nodes. Topology and application changes have to be passed to this service. This information is stored in information databases in the gateways. This is similar to middleware concepts like Jini or CORBA.

Typical in-car networks like CAN or LIN are only implemented up to OSI layer 2 or layer 3 and partly layer 4 in the case of IEEE 1394 and Bluetooth. Therefore adapters can be used to fill the gap to layer 5, the session layer. For IEEE-1394 based networks an adapter was defined meeting the requirements. For CAN CANopen provides connections and an object directory which is necessary for service and application discovery.

1.3.4 Video Transfer over WLAN

For applications that require longer link lengths (30m) like a rear view system for trucks, [9] suggests a wireless link using a 802.11b point-to-point wireless transmission. These applications include parking aids, blind spot avoidance as well as distance warnings. The proposed system consists of two printed circuit boards for each the transmitter and the receiver side. The motherboard connects to the camera or to the display and contains a DSP for real-time video encoding and decoding. The RF unit is placed on the daughterboard. The transmitted full color video is encoded in MPEG 4 with a resolution of 640x480 pixels at a rate of 30 fps. 802.11b which provides a maximum transfer rate of 11 Mbit/s is sufficient for this purpose.

1.3.5 MOST Networks in the Car Industry

MOST Technology is a widely used multimedia network among European carmakers and is already implemented in 38 vehicle models [10]. The different methods and approaches were used. The following text describes available informations about the particular implementations.

- BMW - is a member of a core group responsible for the development process of the MOST technology. Therefore, BMW integrated the MOST into almost all BMW car series as a transfer network for audio signal [11]. MOST technology is used from low-end vehicle variants with a single radio unit up to high end sophisticated navigation system with 14 devices (e.g. BMW iDrive) connected to the bus. The topology of the network is a passive MOST star with a 5-port in-line coupler placed in the trunk of the car. The reason for implementing the MOST Technology as a star is, that the changes in star topology (adding devices) are cheaper then in the ring.

- Volvo Cars - used the MOST Technology in their high-end products. The following models benefit from the MOST multimedia technology: Volvo XC90, Volvo C70 and Volvo S80 [10].

2 AUTOMOTIVE NETWORKS AND PROTOCOLS

This chapter gives a survey of all important networks and protocols which are elaborated and which are important in the automotive multimedia networks. At the end, typically used physical layers and their properties are described and compared to each other with regards to the automotive environment.

2.1 MOST

Media Oriented System Transport (MOST) is an industry standard for automotive multimedia networking [12]. It is a technology designed to provide a network for multimedia automotive applications. The interest of researchers developing MOST is to support heterogeneous multimedia devices and facilitate mutual communication by introducing a low cost peer-to-peer network. Thus a plenty of new multimedia applications for automotive environment can be developed without significant hardware limitations. Behind the inception and the development of MOST technology is an organization called MOST Cooperation (MOSTCO) made up of car manufacturers, component suppliers, system architects and the IT industry. The scope of MOSTCO is to define, promote, and standardize the MOST Technology. Table 2.1 shows how MOST specification covers all layers of Open System Interconnect (OSI) reference model.

By having specified software, hardware and Application Programming Interfaces (APIs), an implementation of multimedia network supporting devices from different manufacturers becomes simpler. Most technology was originally developed to transfer data over the optical physical layer (oPhy), known as a MOST25 (according to the bandwidth). Recently a new specification for the electrical layer (ePhy) was added due to increasing interest in the MOST Technology from the automotive industry. MOST Technology operating over the ePhy is denoted as a MOST50. From MOST Specification point of view, the network model is divided in to three sections: Application section, Network section and Physical section.

2.1.1 Application Section

MOST network supports various devices with wide range of functionality. Starting with simple audio devices like microphones and speakers, MOST networks include video cameras culminating with sophisticated telematics systems. Three different data channels are available for applications:

OSI Layer	*MOST Support*
Application Layer	Application Programming Interface
Presentation Layer	NetServices Layer 2
Session Layer	NetServices Layer 1
Transport Layer	NetServices Layer 1
Network Layer	NetServices Layer 1
Data Link Layer	MOST Transceiver
Physical Layer	Optical/Electrical Physical Layer

Table 2.1: MOST network matching the OSI Model

- Control Channel - The control channel is dedicated for event-oriented transmission with low bandwidth (10 kBit/s) and short packet length. ACK/NAK mechanism with automatic retry is introduced together with CRC secured channels.
- Synchronous Channel - Applications using continuous data streams that demand high bandwidth make use of the synchronous channel. Connection and bandwidth administration is done via Connection manager. All requests for establishing connection are addressed to this block. Connection manager is using functions defined in Function Block (FBlock) ConnectionMaster, which is a compulsory FBlock for each system usually placed in the Timing master device.
- Asynchronous Channel - Transmitting data in a burst-like manner in large block size with large bandwidth.

Logical device model: To connect a device to the MOST Network each device needs to be equipped by a Network Interface Controller (NIC). From the MOST Network's point of view every device consists of Physical Interface, NIC and particular Function blocks.

Functions: Functions are accessible from outside of the Function block via the Function Interface (FI) and can be further divided into three groups (depending on what kind of operation do they perform):

- Methods - are defined as functions which can be started and which lead to the result after a certain period of time. Generally they are triggered only once and are used to control the FBlocks. After a method is called, depending on what kind of operation type do we use (e.g. *start, start/result* [12]), the error or report message should be sent to the initiator.

- Properties - functions determine to change the status of a device i.e. the property of a device. The Operation Types for the properties are: *get, set, increment,* etc. Every property has a one unique state.

- Events - are basically same as properties, the only distinction is that events occur without any external request (e.g. incoming phone call).

Function Block: Each FBlocks contain functions. Every device has a several FBlocks representing the applications (e.g. CD player, Amplifier, etc.) and one mandatory FBlock called Netblock, maintaining functions related to the entire device. We have three different types of FBlocks: slaves, controllers and HMIs. Slaves are always controlled FBlocks, controllers are FBlocks using functions in another Function Block and HMIs are FBlocks communicating with the user. By using the delegation, heredity and device hierarchy methods, the complex system can be controlled in an understandable way [12].

Communication on application layer: Protocols on the application layer are described universally; hence communication on application layer is independent of the implemented physical medium. Figure 2.1 shows virtual and real communication between two devices on the application layer. Virtual communication is realized directly in between two applications and demonstrably real communication is done via network service and MOST NIC. All application protocols are transferred firstly into Network service block.

- Communication with Properties - By having defined the controller and slave previously the communication with properties is done by using shadows. The controlled device (slave) has its properties defined in FBlock, where the controller can operate these properties via the same FBlock shadow located in the controller.

- Communication with Methods - Communication by using a shadow is not sufficient for the methods anymore, since the methods can have more then one state. When the method is triggered, the process last for a certain period of time, hence the operation types with acknowledgements are introduced.

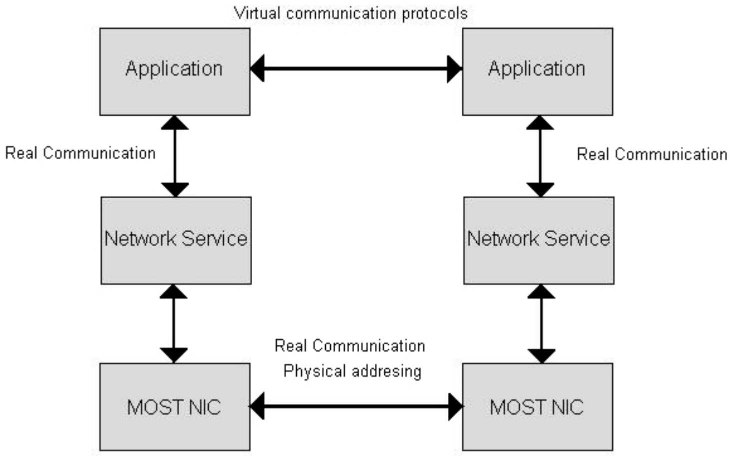

Figure 2.1: Virtual and real communication between two devices

2.1.2 Network section

MOST Network Interface Controller: MOST Network can be implemented as a star-, ring- or daisy-chain topology. As described earlier MOST Network Interface Controller (NIC) is a mandatory part of each connected device to the MOST Network. The following part will give an overview of functions of NIC.

- Bypass - Each device has its own bypass function. If a bypass is activated, data coming from the input interface are transferred directly to the output interface. As a result, the device is passive and from the MOST bus point of view therefore invisible.

- Source data bypass - As soon as the device wants to send an item of data a source data bypass must be opened.

- Timing Master (Frame Generator) - The MOST Network can be maximally connected with 64 NICs, thus maximally 64 devices. In order to establish communication, one of those devices must become a Timing Master. The main task is to generate and transport the system clock, the blocks and frames. Other devices (timing slaves) are synchronized with the Frame Generator by using internal PLL (Phase-Locked Loop). By having all the devices synchronized to the network no memory buffering is needed.

Data Transport: Data transport includes mechanisms for network delay detection, burst data channel management, and automatic channel routing. The sample frequency can be chosen between 30 kHz and 50 kHz.

Optical physical layer: When using optical physical layer, data is transported in continuous bi-phase encoded bit stream at 24.8 Mbit/s and 44.1 kHz rate. Bit error rate (BER) is ensured at less then 10^{-10}. Data stream consists of blocks further composed from particular Frames. This structure is required for network management and transport of control data. Each Frame has 512 bits where one Block contains 16 Frames. One frame has 60 Bytes of data available for synchronous and asynchronous packet data transfer and 2 Bytes transfer control data. Remaining 2 Bytes are added to the control frame to transport a control telegram. The structure of MOST25 data frame is depicted in the Figure 2.2.

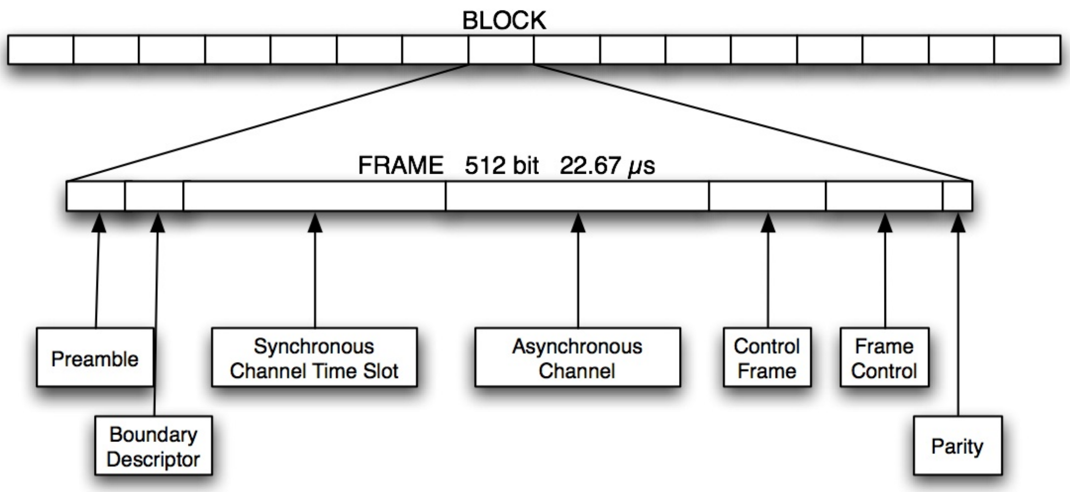

Figure 2.2: Structure of MOST25 Data Frame

Electrical physical layer: Recently released specifications for the electrical layer can transfer data at 50 Mbit/s [13]. MOST50 frame consists of 1024 bits, where the first 88 bits are used for control data (4 Bytes) and for other administrative functions. For the synchronous and the asynchronous data transfer the remaining 117 Bytes are used. The MOST50 frame is depicted in the Figure 2.3. Vendors are developing new INICs operating over optical layer with data rate 150 Mbit/s.

Data Frame: Structure of data frames are shown in Figures 2.2 and 2.3. The particular parts are described in the following section.

- Preamble - is used to synchronize the MOST nodes and its functions to the bit stream. Two different mechanisms of synchronization are implemented. First is for slave nodes and is done by reception of the valid preamble. This method results in slave node beeing locked to the timing master (phase and

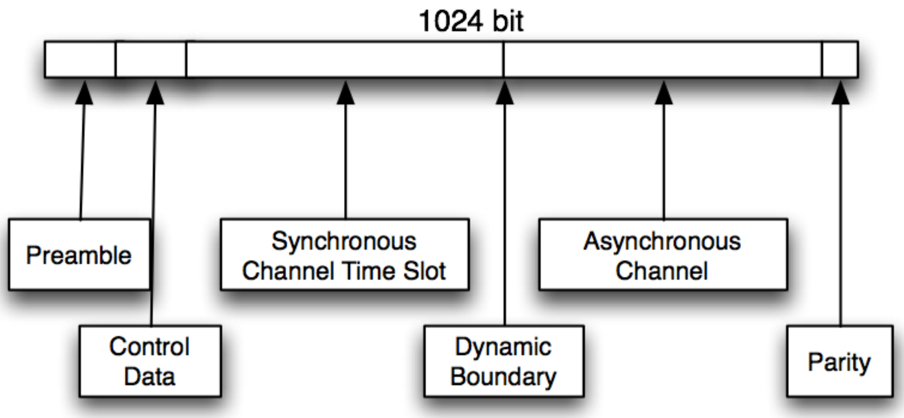

Figure 2.3: Structure of MOST50 Data Frame

frequency). Second mechanism is for master (timing) node, where the bit stream is synchronized to the external clock source (e.g., crystal oscillator, S/PIDF source).

- Boundary descriptor (BD) - The boundary descriptor determines the ratio of allocated memory between the synchronous and the asynchronous part in each frame. Two different implementations of BD are specified:

  1. MOST25 - as mentioned previously, 60 Bytes of data in each frame are available for asynchronous and synchronous transfer. One quadlet (4 Bytes) of data in synchronous part is dedicated to boundary descriptor. The range of allocated memory is determined by position of BD between quadlets 6-15. This means, that maximum number of asynchronous data per frame is 36 Bytes (BD = 6) and maximum number of synchronous data Bytes per frame is 60 Bytes (BD = 15). During the transmission the timing master node is responsible for controlling and administrating BD.
  2. MOST50 - A dynamic boundary method is used in the MOST50 frame. The dynamic boundary allows the system to change the streaming data during the data transfer dynamically. The only authorized device to realize this change is an application in the timing master. The maximum amount of data for packet oriented transfer is 116 Bytes/Frame.

- Parity - Parity control frame is employed to control the content of data, error detection and PLL operation.

- Synchronous area - Allocated time slots for synchronous channel are used for real-time data transmission (audio/video, monitoring, sensors). The Time Division Multiplex (TDM) method with allocation of quasi-static physical channels for different periods of time technique is implemented. Maximum number of bites for the MOST25 is equal to 60x8 bits/frame with the used rate 44 100 frames/s. For the MOST50 frame the maximum number is 117x8 bits/frame with 48 000 frames/s.

- Asynchronous area - Two different mechanisms for transfer of asynchronous (packet) data are realized. Firstly transfer of slow asynchronous data (e.g. telegrams to control devices) which is used control channel of the MOST Network Interface Controller. Secondly, faster packet-oriented transfer done via an asynchronous channel designed to handle burst like traffic. Access method for this channel is implemented in token ring fashion; the maximum packet length is 48 Bytes. Hardware CRC protection is calculated and is assigned to the end of each asynchronous message.

- Control data - For communication between single nodes on the bus the control data channel is used. Carrier Sense Multiple Access (CSMA) mechanism is employed for accessing the data channel. Two kinds of control messages are used. Normal messages, to provide a control of applications (commands, status and diagnosis messages) and system messages for system administration (resource handling). Arbitration is provided automatically by MOST NIC.

2.1.3 Physical section

MOST Network uses mechanism of actuating. Device can convert it's mode in to sleep mode, where the consumption of energy is low (I $\leq$ 100 μA).

The following text describes particular sections of the MOST device structure.

- Interface Area - Consists of a transmitter (TX) and receiver (RX) communicating with NIC. During a data transmission the phase jitter can be accumulated, hence this factor together with power budget is rigorously considered during the design of Optical Interface Area.

- MOST Function Area - Network Interface Controller, crystal and PLL-Filter are the main blocks in MOST Function Area. NIC communicates with μController via I2C (Inter-Integrated Circuit), SPI (Serial Peripheral Interface) or parallel bus.

- μController Area - microcontroller (μC) and memory is a usual content of this optional block.

- Application Area - Belongs to the application peripherals (i.e., receiver, amplifier).
- Power Supply Area - Consists of different facilities performing various tasks (e.g., EMI/EMC protection, Micropower regulator, watchdog timer, etc [12]).

Optical Physical Layer: As mentioned earlier, the MOST Network was originally developed and designed to operate over the plastic optical fibres (POFs) as a physical layer. This took abroad various pros and cons. In that time the certain advantages were an Electro-Magnetic Interference (EMI) immunity and light weight. On the other hand, small bend radius and limited temperature range were the two most significant imperfections from the automotive point of view [14]. MOST technology utilization was increasing by implementing this multimedia network into luxury modern cars. The used optical medium for the MOST25 is POF/LED.

Electrical Physical Layer: The automotive progress is becoming more and more focused on the electronic area and carmakers are competing between each other in providing more superior and sophisticated multimedia services. Under these conditions the needs for multimedia services in budget-range cars and for new physical layer (ePHY) arise. Simultaneously with new electrical physical layer the Intelligent NIC (INIC) was introduced [15]. As a transmission medium Unshielded Twist Pair (UTP) cables are employed. From preceding text one problem arises, which is the Electro-Magnetic Compatibility (EMC) in automotive world.

EMC Testing The following part summarizes the most significant improvements in order to reduce EMI in ePHY.

- Improved signal skew by usage of common mode filter [16].
- Power between physical layer and NIC was decreased (from 5 V to 3,3 V and 2,5 V [11]).
- Differential signalling, filtering and scrambling of the signal was introduced.
- Size and number of high-speed traces in Printed Circuit Board were reduced.

MOST50 was individually tested by several carmakers. The list of the passed standards can be found in [10]. Different kinds of UTP cables with the twist length $\leq$45 mm and impedance of 100 Ω were tested. Standard automotive connectors (e.g. crimp style connector with 4 or more pins [10]) can be used.

The Intelligent Network Interface Controller for MOST was designed to facilitate the integration of the new electrical physical layer. Significant benefits are:

- Doubled transmission rate from 25 Mbit/s to 50 Mbit/s in MOST50.
- High number of interconnects (up to 8 in-line couplers per link between 2 devices).
- Utilization of current manufacturing processes (UTP cables).
- Simple manipulation.

New signal circuitry provides differential input and output directly interfacing with the ePHY transformer. The INIC contains its own microcontroller and mini-kernel to implement the function from Network Service Layer 1 and NetBlock from Network Service Layer 2. Originally in NIC a register wall was used as an interface.

As it was stated, the MOST Network is a dynamically developing technology. This paragraph draws up the future development trends and directions.

- MOST 150 - Is a next step in the development process with a higher bandwidth (150 Mbit/s) based still on the POF/LED. Carmakers like BMW or Daimler Chrysler tend towards this solution, since the already well known and tested POF/LED can be utilized. However 150 Mbit/s seems to be as the highest possible value over POF and LED. For more bandwidth a new optical transceivers will be used. It is expected, that the MOST150 ring will transfer multiple sound and compressed video signals simultaneously.
- MOST 1000 - In order to increase the bandwidth, the PCS/VCSEL physical layer will be utilized. The MOST1000 is a technology for long time consideration and its introduction is not expected within the next 10 years.

2.2 SAE J1939

The CAN-based SAE J1939 bus was developed for diagnostics and component control applications in truck and trailer systems like radar and lidar, and engine, transmission and EBS electronic control modules. This SAE class C network supports real-time closed loop control function between ECUs [17].

2.2.1 Physical Layer

OSI layer one and layer two are identical to the CAN 2.0b standard. The physical medium can be both shielded (SAE J1939-11) and unshielded (SAE J1939-15) twisted pair of copper wires. The maximum bus length is 40 m, terminated with a resistor at each end to reduce reflections, with a maximum data rate of 250 kBit/s. The ECUs may be in direct contact with the bus, or via short stubs. No loops are allowed, although redundant bus segments can be provided for fault tolerance. In this case the corresponding ECUs must be able to deal with these redundant wires. To provide electrical isolation and compatibility of different data rates and physical media between segments like tractor, trailor or implements, bridges are used. J1939 supports up to 30 ECUs per bus segment if STP wires are used, in the case of UTP this number is reduced to 10 [18, 19].

2.2.2 Data Link Layer

SAE J1939 uses the CAN 2.0b extended frame format with 29 identifier bits in the arbitration field [20]. The first three bits define the priority of the message. This field is followed by a reserved bit which is set to zero and the data page bit which extends the parameter group extensions. The next eight bits define the PDU format followed by 8-bit PDU specific field. If the PDU format field has a value of 0-239 (PDU1) the PDU specific field will contain the destination address of the frame, on the other hand with a value of 240-255 (PDU2) it contains the group extension. Therefore a total of $(240 + (16 * 256)) * 2 = 8672$ parameter groups are possible. Most messages sent in a J1939 network are of the later type and therefore they are broadcasted. The source address also consists of eight bits which is sufficient for 256 devices. Addresses are usually preassigned, but if necessary, there is also a procedure for assigning addresses available. Finally the data field provides eight bytes. If the message is longer, up to 1785 bytes, a transport protocol function is used and the message is divided to multiple CAN data frames.

The parameter group number defines five message types, which are:

- Commands, such as "Transmission Control"
- Requests
- Broadcast/Response
- Acknowledgement in the form of in-frame ACKs, which indicates that at least one node has successfully received the message and as a response to a request.
- Group functions, which contain proprietary functions or network management

Bus access, arbitration and error correction are handled as specified in CAN.

OSI Layer	*SAE J1939*
Application Layer	SAE J1939/71
Presentation Layer	not specified
Session Layer	not specified
Transport Layer	not specified
Network Layer	SAE J1939/31
Data Link Layer	SAE J1939/21, CAN 2.0b
Physical Layer	SAE J1939/11, SAE J1939/15

Table 2.2: SAE J1939 network matching the OSI Model

2.2.3 Network Layer

The function of the network layer is to transfer messages from one segment to another [21]. Furthermore the J1939 network layer provides database management functions to access and to configure databases within a network interconnection ECU (NIECU). There is a NIECU for each network segment. These segments can be tractor, trailer, implement or subnetworks such as brakes. The NIECU acts as either a repeater, bridge, router or gateway. Therefore one or more of the following functions are provided:

- Forwarding messages from one segment to another segment
- Filtering to reduce bus traffic on a given segment as messages which are not meant for a segment can be blocked by the NIECU
- Address Translation, where a single address can be used to reference a particular system like the trailer, due to a look-up table with the associated source/destination address located in the NIECU

- Message Repackaging, which provides a potential reduction of bus traffic as several parameters can be grouped more efficiently

- Database Management to access and configure databases in the NIECU such as the static filter database

2.2.4 Vehicle Application Layer

In the vehicle application layer of SAE J1939 all the parameter groups as well as the parameter group numbers are specified. The parameter group number is a unique identifier for each CAN message [22]. Furthermore a "source address of controlling device" parameter was added in the last revision which makes it possible to identify the original source of a message in a bridged network.

2.2.5 Network Management

Network management covers all OSI layers [23]. This layer defines various state diagrams for instance for initialization and it defines constraints on the use of addresses.

2.3 IDB-1394

IDB-1394 is an automotive version of the IEEE-1394b standard, a high-speed bidirectional serial bus usually used for digital video cameras, hard discs and other high-speed devices, extended by higher level protocols [24]. For automotive applications either plastic optical fibres (POF) or hard clad silica fibres (HCS) are applicable. Depending on the physical medium, maximum transmission rates of 100 Mbit/s and 200 Mbit/s over a link length of 50 m (POF) and 100 m (HCS). Using shorter link lengths increases the transmission rate up to 400 Mbit/s and soon up to 1600 and even 3200 Mbit/s.

The standard supports up to 63 nodes per bus including a consumer convenience port, automatic node identification and topology configuration. IEEE-1394 also supports both isochronous traffic with guaranteed latency and bandwidth which makes it suitable for real-time applications and asynchronous traffic. The physical topology of IEEE-1394 can be a bus or "daisy-chain" and a tree. In the automotive version IDB-1394 additionally a ring topology is possible, which is the suggested topology here as it provides a reliable level of system availability. Each IEEE-1394 device provides at least two connectors.

2.3.1 IDB-1394 Specification

IDB-1394 specifies OSI layer one to layer five. The first three layers, except the IDB-1394 protocol also meet the IEEE-1394 specifications [25].

- Physical Layer including the CCP (Consumer Convenience Port, which provides an interface, used for portable devices)
- IEEE-1394 stack and driver: The driver acts as the hardware device driver whereas the stack is responsible for bus management, isochronous resource management and isochronous and asynchronous transaction management.
- Higher-level protocols: This protocols include the communication management protocol IEC-61883, which defines the format in which audio and video data are transported, and the AV/C controller which defines control messages for audio and video and descriptors for their presentation. Furthermore the IDB-1394 protocol, designed for automotive requirements, is located in this layer. It initiates on request the sleep-mode and the wake-up signal for embedded network devices.

- Communication layer: This layer acts as the automotive message transport layer and provides interfaces between different networks and protocols like Bluetooth, IDB-1394 or CAN.

OSI Layer	*IDB-1394*
Application Layer	not specified
Presentation Layer	not specified
Session Layer	not specified
Transport Layer	Network Adaption Layer
Network Layer	AV/C, VIP
Data Link Layer	IEC-61883
Physical Layer	IEEE-1394

Table 2.3: IDB-1394 network matching the OSI Model

2.3.2 Topology Configuration

Adding and removing devices from the CCP or the dynamic power management causes a (re-)configuration of the network. The configuration consists of three steps [26, 27]:

- Bus Initialization: Any bus topology information in all nodes is cleared. Each node knows only if it is a leaf or a branch.
- Tree Identification: Each node assigns its ports to be connected either to a parent or a child. The node which is only connected to children is the root node.
- Self-identification: The root node and all the children nodes recursively request self-identification from their children node. This includes information about speed capabilities and port connection status. Also each node gets a bus address. After the self-identification the bus topology is broadcast to all nodes.

2.4 APIX Link

The Automotive PIXel Link was developed by Inova Semiconductors [28, 29, 30] in cooperation with the *Fraunhofer Gesellschaft* in spring 2005. The link was the answer to the car industry's question if GigaSTaR (Gigabit-Serial-Transmit and Receive), which offers data rates of up to 1.2 Gbit/s over a pair of copper wires can be used in automotive applications. GigaSTaR is currently utilized for passenger information systems in trains, to connect remote terminals in the automation industry, as well as for modern LED video walls. The high requirements of the car industry concerning EMI and EMC were not fulfilled by GigaSTaR. Therefore Inova Semiconductors developed APIX to meet these demands.

The APIX point-to-point link is based on a one or two pairs of STP copper wires and transmits uncompressed pixel data with a data rate of up to 1 Gbit/s on the downlink and up to 62.5 Mbit/s on the upstream link over a wire length of 15 m. One big advantage of APIX compared to optical networks like MOST or IDB-1394 is that optical-to-electronic and electronic-to-optical converters on each device, which produces rather high cost, and comparable unflexible POFs can be avoided. The transceiver and receiver chips are produced in a 0.18-μm-CMOS process which keeps the purchasing costs low. Also the energy consumption is as low as 200 mW and the possible application area covers a temperature range from -40 °C to 105 °C [31].

Due to special IOs, adjustable driving current and pre-emphasis, new spread-spectrum clocking and an optimized PLL concept, a very good electromagnetical compatibility of the link is ensured. The APIX link only specifies the physical layer.

APIX provides a continuous real-time data stream with low latency and low BER, running for instance at 1 Gbit/s for the high-resolution, full-colour display link between the image processor and the TFT display or 500 Mbit/s on the camera link between the CMOS sensor and the processor. The camera can be monitored and controlled with the integrated back channel simultaneously. Altogether the APIX link consists of three independent channels: the unidirectional downstream pixel channel and the bidirectional side band channels. All channels can be multiplexed and transmitted over a single STP wire. The upstream side band channel could also be established over a second pair of wires. One application for these additional side band channels is to transmit other protocols 'piggyback-like' without the need of buffers. These protocols can be used to monitor and control parameters of the CMOS sensors and displays.

Applications for the APIX link as proposed by Inova Semiconductors are for instance dashboard, rear seat, or head-up displays as well as cameras for lane departure warning, adaptive cruise control, rear and side mirror replacement and blind spot detection. Large 24-bit full-colour displays with a resolution of 1280x480 pixels are said to replace the analogue dashboard in the near future.

Several press releases like [31] say that APIX' safe and EMC-optimized physical layer will be a good basis to meet the requirements for the next decade. A large number of suppliers have already started to integrate the APIX functionality in their chip sets.

3 PERFORMANCE REQUIREMENTS

3.1 Performance Requirements and Characteristics of Automotive Multimedia Systems

Automotive Multimedia systems have different requirements when compared to multimedia systems in general. In this chapter we elaborate on the important aspects, which influence the design of new networks and technologies in automotive environment. These aspects comprise all technical and business characteristic features. The aspects are divided in to two groups as depicted in Figure 3.1. The first group contains common requirements of automotive electronic systems and the second group performance requirements of the current Automotive Multimedia Systems. In other words, requirements on automotive electronics will be characteristic properties of designed multimedia network. The first group should be deeply investigated before any introduction of new technology in the automotive industry [2].

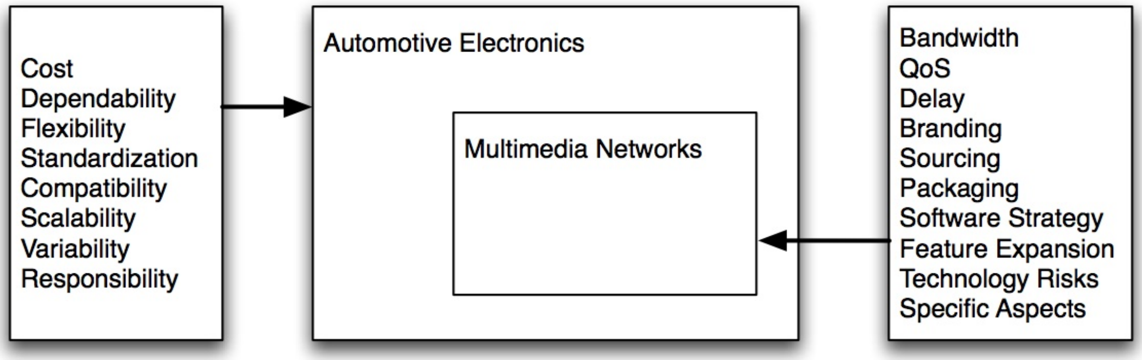

Figure 3.1: Performance requirements

3.1.1 Requirements of automotive electronics

Cost

The electronic systems are already necessary parts of all automotive applications and the cost of electronics in the total cost is predicted to be about 40% [2]. Cost-efficiency presents a crucial aspect during the development process. In automotive industry cost is affected by competitive market, mass production and lifespan of vehicles. Another important aspect influencing the cost from long term point of view is, that the new technology has to be sufficient in the future development processes. Generaly the automotive producers want to be cost-efficient as much as possible. Hence they aim to decrease development, production and maintanance costs of their products on the lowest possible level. An important point is to consider that the cost-efficient system has also to satisfy its future requirements.

Dependability

Dependability can be further divided into the following aspects [2, chap. 3].

- Reliability and Availability- both factors are closely related to each other. Nevertheless one important divergence is that reliability guarantees correct functioning over a given period of time and availability guarantees this operation in any time.
- Safety is undoubtedly decisive factor when choosing a new technology. When having a safety parameter in mind, one can think about faults, errors and system failures. More information on how to solve and prevent different situations can be found in [2].
- Confidentiality is a crucial aspect in the competitive automotive industry. Therefore it is not convenient to disclose any confidential information, unless it is a purposeful step, where the informations are shared (e.g. platforms in the car industry)
- Maintainability is an important factor not only for seamless functioning during product lifetime, but also various repairs, improvements and changes in the system can be performed.

Flexibility

Flexible arrangement of the system provides the possibility to improve and change existing functionality and topology. Flexible arrangement can be achieved by using platforms and layered structures. The flexibility is important for the automotive electronics as well as for the multimedia networks. The flexible system usually decreases the cost during performing any changes and improvements.

Standardization

The automotive industry visibly desiderates open standard solutions. Many manufacturers in automotive area are developing their own solutions. With open standards solutions development process can be divided into more companies, hence the cost can be decreased. As all industry developments have their own advantages and disadvantages, every little improvement of the open source system will be beneficial to all involved manufacturers, which does not have to be desirable. The most visible organization in automotive standardization is AMI-C (Automotive Multimedia Interface Collaboration). In the interest of AMI-C is to adopt already existing standards on the market to the automotive industry, primarily in multimedia networks (i.e. MOST, IDB 1394, Bluetooth). Standardization generally refers to streaming media and communication interfaces. MOST Network and AUTOSAR (AUTomotive Open System ARchitecture) are technologies developed as a standard from the beginning. Behind those two projects are standing different groups of carmakers and manufacturers.

Compatibility

Compatibility can be increased by standardization process (e.g. defining various interfaces and gateways to communicate with other external devices or systems) and is an important aspect bringing the cooperation between various producers. Generally compatible technology brings benefits for suppliers, automotive producers and customers.

Scalability

Scalable systems are systems whose functionality improves, when new devices are added. Translated into my topic, scalable automotive electronics system has to demonstrate improved performance after adding new additional hardware or software. These changes are mostly related to the future improvements of the electronic systems. A scalable systems should satisfy requirements, when new services and technologies are introduced and implemented. Thus, researchers in automotive electronics aim for predicting the future trends and development as much as it is possible and encompass them in the development process. Obviously this is not an easy process, as simply introducing of new technologies can not be predicted. However a reasonable trade off between expected growth trends and possible current solution should be considered carefully. In the forth part of this theis, the scalability is associated with the network topology and with the possibility to improve particular technologies.

In the MOST Network, which is described in detail in first phase of this project, when the researchers introduced new electrical physical layer (ePHY), mean that changes were necessary in Network Interface Controllers (NICs) and Network Services (Layer1 and 2). From these facts we can observe to what degree the system is scalable.

Variability

Variability is defined as a capability of the system to be configurable with respect to the special demands of the customers [32]. Electronic system must be available in configurations to be implemented in different models. The importance of this aspect in automotive industry is evident, since the demands of customers for various combinations are well known. In the automotive area the customer's demands vary as well as the devices connected to the multimedia networks and their topology. The proposed system should be identical with these changes and their realization as cheap as possible.

Responsibility

Responsibility is an important aspect when choosing various device suppliers. If the car manufacturer decides to implement many of complex devices from external suppliers in his product, the responsibility for functioning of the device will rely on the suppliers. This solution is usually not cost effective for the company and reasonable trade off between suppliers' products and companies' technical solutions has to be chosen. The designed system can become extremely expensive, when the suppliers will perform all small changes and repairs in the system. On the other hand the technologies are usually very complex, hence the automotive producers can not invest their resources into the development process of all used technologies.

3.1.2 Requirements of Telematic and Infotainment systems

By having in mind the growing importance of Telematic and Infotainment systems in automotive applications, requirements on multimedia networks driven by these systems, from carmakers point of view, are highlighted in the following subsection.

Bandwidth

Bandwidth belongs between the major aspects in multimedia networking area. Different solutions have been proposed in order to provide higher bandwidth and to allow superior services (e.g., streaming video). With the introduction of new network technologies the bandwidth will unambiguously increase, since the applications demand a large amount of data to be transmitted on-board. Generally today's state of the art does not provide satisfactory solutions for implementing all services.

QoS

Quality of Service should be also considered when a complex multimedia network is proposed. Priorities in the packet switched data networks should be determined to improve network throughput.

Delay

Delay of data packets and variance of the delay (delay jitter) plays an important role in the networking area. Therefore these aspects must be considered along the development process.

Branding

When a new device is delivered by a supplier, the car maker usually does not want to have a supplier's brand written on the device. Therefore a branding stands for replacing all supplier's related trademarks and logos by car maker's own brand.

Power Supply

Different power supply schemes and strategies can be implemented. This factor affects the final solution. Generally two approaches are used. The first is to use a separate cable for the power supply and second is to use the electrical communication medium as a source of energy. This can reduces a number of used cables in the vehicles, but demands more complicated transceivers.

Packaging

This aspect is related to different device topologies. One solution can represent a complex device supporting many services and other solutions can be a distributed topology of a device providing various services not just from one device box. The complex device is easy to implement in to the vehicle, but it is not possible to change the functionality nor the topology of the system. Such a complex device can be represented by one box with all the required functions and features.

In the distributed solution a communication network acts as a transfer medium for the particular devices. Therefore adding new features and services is possible and all of the devices can benefit from their mutual communication. The distributed solution brings another issues into the consideration e.g. compatibility, responsibility, etc.

Software strategy

Automotive producer has to look at heterogeneous aspects during the implementation of new technologies. Software strategy is a factor which affects other aspects such as the cost and the packaging. By software strategy it is meant different approaches with regard to the implementation of software. One approach can be tried involving a trade off between supplier's software implementation and the carmaker's software solution. The second approach deals with placing the software parts into the various places in the system (i.e. some applications can be placed in the central device and some in the particular parts in the network). The software strategy is closely related to the responsibility, hence these aspects should be clearly defined during a cooperation with a supplier.

Feature expansion possibility

This aspect is closely related to the scalability. To emphasize the significance of scalability in infotainment systems, feature expansion possibility features are placed in this group. An importance of this aspect is visible, since the multimedia devices are dynamically developing and new features and functions are introduced. New introduced technology should be able to support functions and features introduced during the period of the technology's lifetime.

Technology risks

Technology risks can occur when introducing new technologies, which were not sufficiently tested and which for example are unlikely to become the standard or major track in the industry. The automotive manufacturers are guarding against taking undesirable technology risks and are rather careful in implementing revolutionary technologies. Based on these facts, one can begin to understand the conservatism which is prevalent in the automotive industry (e.g. vehicle's combustion engine etc). Generally car makers are quite conservative when it comes to new technologies because 'new' implies untested and therefore unknown risks. The technology risks is in the automotive industry increased by the fact, that the devices in the vehicles face to the specific conditions (e.g. temperature, shakes, etc).

Specific Aspects

In this paragraph specific aspects which affect the development process are mentioned. These aspects are considered during the technologies development processes and are related to the physical layer:

- Temperature range

- BER (Bit Error Rate)
- SNR (Signal to Noise Ratio)
- Crosstalk
- EMI (ElectroMagnetic Interference)
- Inductance
- Capacitance

3.1.3 Relations between aspects

All aspects mentioned above should be considered carefully during a development process. Various relations between aspects can be theoretically observed and more relations appear during the implementation procedure. Generally speaking the most dependable aspect or most related aspect, both from the automotive manufacturer's point of view is the cost (e.g., in order to have a cost-efficient product the sufficient degree of scalability must be guaranteed).

4 EVALUATION OF DIFFERENT TOPOLOGIES

In this chapter various networks and their topologies are described and presented as my proposed solutions. The aspects mentioned in the previous chapter are compared with the proposals. Therefore a general evaluation of the proposed networks and their comparisons are given.

4.1 CAN-based Networks

4.1.1 Typical Multimedia Topology for Vehicles

Current architectures of multimedia networks in cars, include typically an integrated CAN-based bus (e.g. J1939) as the usual communication medium. In reality the current multimedia network is presented by audio, phone and HMI devices connected together. In Figure 4.1 is illustrated the typical multimedia architecture. From Figure 4.1 results the need for changing the topology of current network. The problem is, that the bandwidth of the CAN-based network is limited (250 kBit/s) and adding the new devices (e.g. DVD, Navigation, etc.) is becoming an impossible task. This is depicted in the Figure 4.1 and a possible solution for this problem is described in the following section.

4.1.2 Description

Figure 4.2 shows how the possible implementation of a CAN-based multimedia network could be done. Particular devices are connected to the CAN bus and the multimedia signals are transported over separate cables. A CAN-based network (e.g. J1939) is used to send the control data between devices. The control data can be theoretically used from the J1939 specification or can be defined as proprietary messages. Another possibility will be an implementation of control messages from automotive network designed for multimedia (e.g. MOST). The sound signal is transferred through an ordinary audio RCA cable connected to the AUXiliary Input/Output interface. For video signals the video RCA cables can be used. Uncompressed video signals from cameras and navigation unit are connected to the Video Switch (VS) and depicted on the 2nd display.

4.1.3 Communication

Communication via the common shared bus depends on the implemented control messages. For example in the case of utilizing the MOST control messages the communication will be identical to the communication over the control channel in

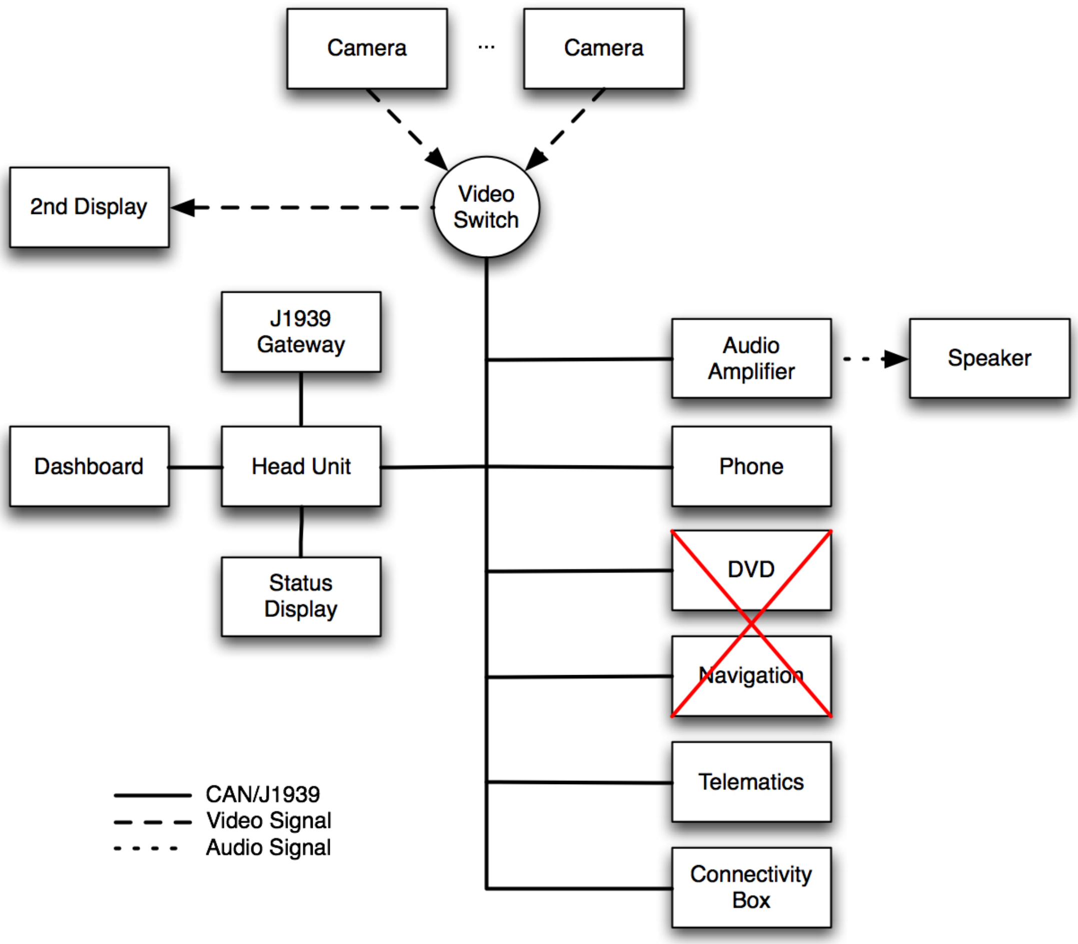

Figure 4.1: Insufficiency of CAN bus as a multimedia network

Section 4.2.3, where instead of allocating channels on the bus, the direct cables will be used. For any other solution the content and structure of control messages will determine the way of communication. Video signals have to be treated separately. The content shown in the 2nd display can be chosen by manual change of the switch position, or as a reaction on some event eg by selecting the navigation unit in the HMI, the navigation signal should be shown automatically or during shifting to the reverse gear a back camera would be activated. The cameras are connected to the video switch and the content shown on the 2nd display is hence chosen by changing the position of the switch.

4.1.4 Aspects

The properties of this CAN-based solution are described in the following section.

- Cost - At first sight the cost of this proposal is relatively low, since there is no

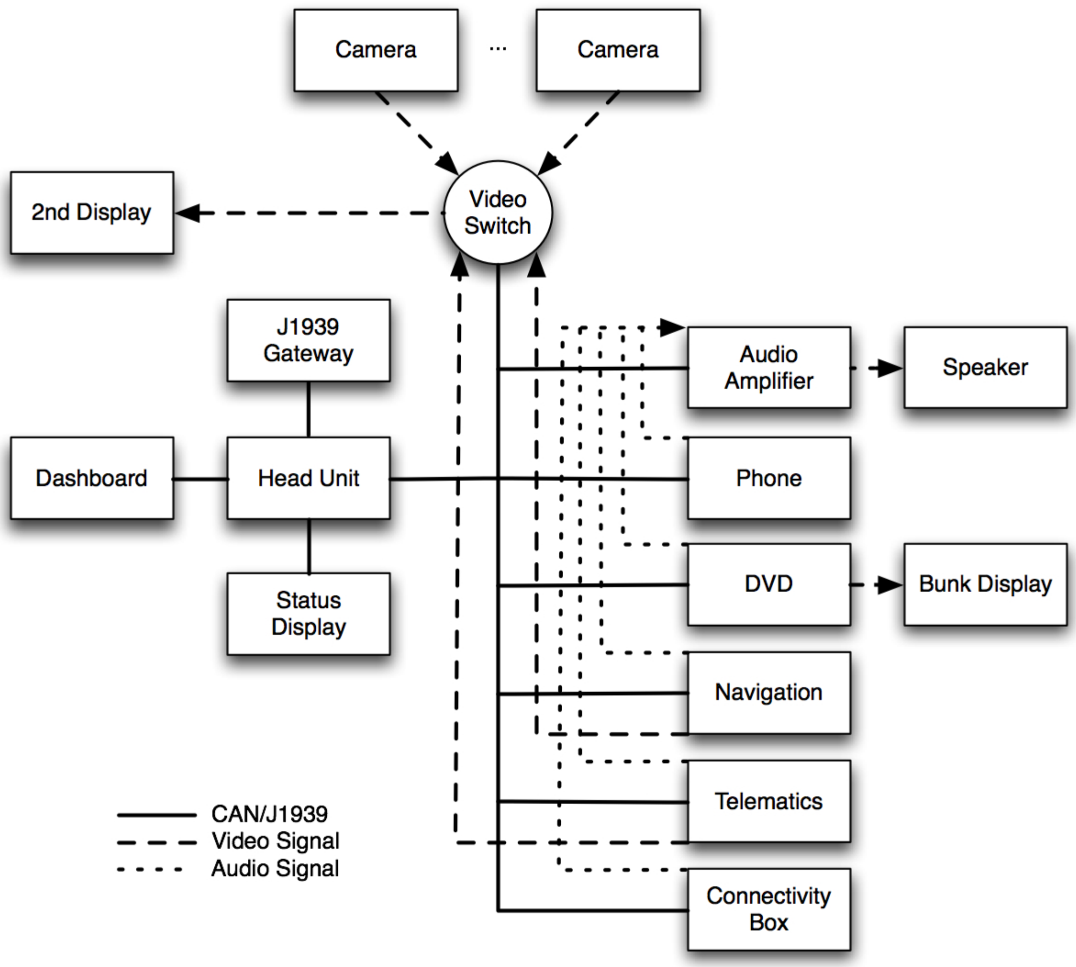

Figure 4.2: CAN-based solution

new technology introduced and the used devices need to undergo just minor changes. As defined in the Section 3.1.1 the future benefit of the solution is closely related to the cost, hence the cost of this proposal is significantly increased by this factor.

- Scalability - This solution is not very satisfactory in terms of the scalability. By adding a new device the whole topology has to be changed and new interfaces to connect the device need to be added. This has a further implication in bringing in an undesirable increase in the number of the cables and interfaces, which in turn may increase the cost.
- Variability - Variability can be ensured by connecting particular devices to the network. This increases the number of used cables and interfaces.
- Dependability - Reliability, availability and safety are ensured by the used

control channel, in both possibilities (i.e. the MOST control messages and the proprietary control messages) are those aspects guaranteed.

- Flexibility - The flexibility of the solution is decreased by the facts that the signals are transferred via different cables and the possibility to change the topology or introduce a new function useful for more then one device is impossible.

- Standardization - CAN is a standardized technology as is the transfer of the audio and video signals via RCA cables

- Compatibility - This solution is compatible with the surrounding technology (CAN network) and for the functional part the connectivity box with different interfaces to connect audio devices is present.

- Responsibility - The responsibility is predominantly on the side of the automotive manufacturer. No sophisticated devices are implemented and the control mechanism can be maintained by the carmaker.

- Bandwidth - As it was written in the Section 4.1.1 the bandwidth limitation was an obstacle for using the CAN bus to transfer all signals. Hence, the solution with separate cables partially solves this bandwidth problem.

- QoS - Quality of Services are guaranteed by the technology used in the control channel.

- Power supply - The power supplies are designed separately.

- Packaging - A distributed approach in CAN network is applied.

- Software strategy - Depending on the suppliers, a distributed or uniform software strategy can be chosen. From the communication point of view, the distributed version is more viable, since the communication channel between the head unit and the devices is limited and only control data can be exchanged. For example a software part of a navigation unit has to be placed in the device and can not be as a part of the head unit.

- Feature expansion possibility - This aspect is very limited, not only because of the low scalability, but also the features of particular devices are restricted.

- Technology risks - Technology risk is low, because of already known used CAN technology. Nevertheless implementation in the new environment (multimedia) can cause unexpected problems.

4.1.5 Summary

At first sight this solution looks as a promising because of its cost and compatibility. On the other hand there is a lack of scalability and feature expansion possibility. Primarily these two aspects decrease the evaluation of the network, since the insufficiency in satisfying new technologies is known. Another disadvantage is that adding more devices causes more cables and interfaces, which is becoming a problem in the automotive environment today. In addition the particular devices can neither benefit from mutual communication nor provide sophisticated services based on exchanging signals with multimedia content. In other words the absence of fully integrated network brings the advantage of low implementation cost, nevertheless the above described disadvantages should be taken in to account.

4.2 MOST50 Network

4.2.1 Description

In this proposal a possible implementation of the entertainment subnet is described in detail. Figure 4.3 depicts the topology of my suggested multimedia network. This solution benefits from recently introduced ePhy for the MOST technology known as MOST50. Devices are connected to the most bus via INICs. As it is shown in the Figure 4.3, heterogeneous devices connected to the bus create a ring topology of the network. The bus is used to transfer the control, audio and compressed video signals. Video signals are present in the navigation unit and cameras. Depending on the location of cameras and on the chosen approach, the version with a video switch and connected cameras via RCA or coaxial video cables is shown in the proposal. Another method is to connect the cameras to the MOST ring and to send the compressed video signal over the bus.

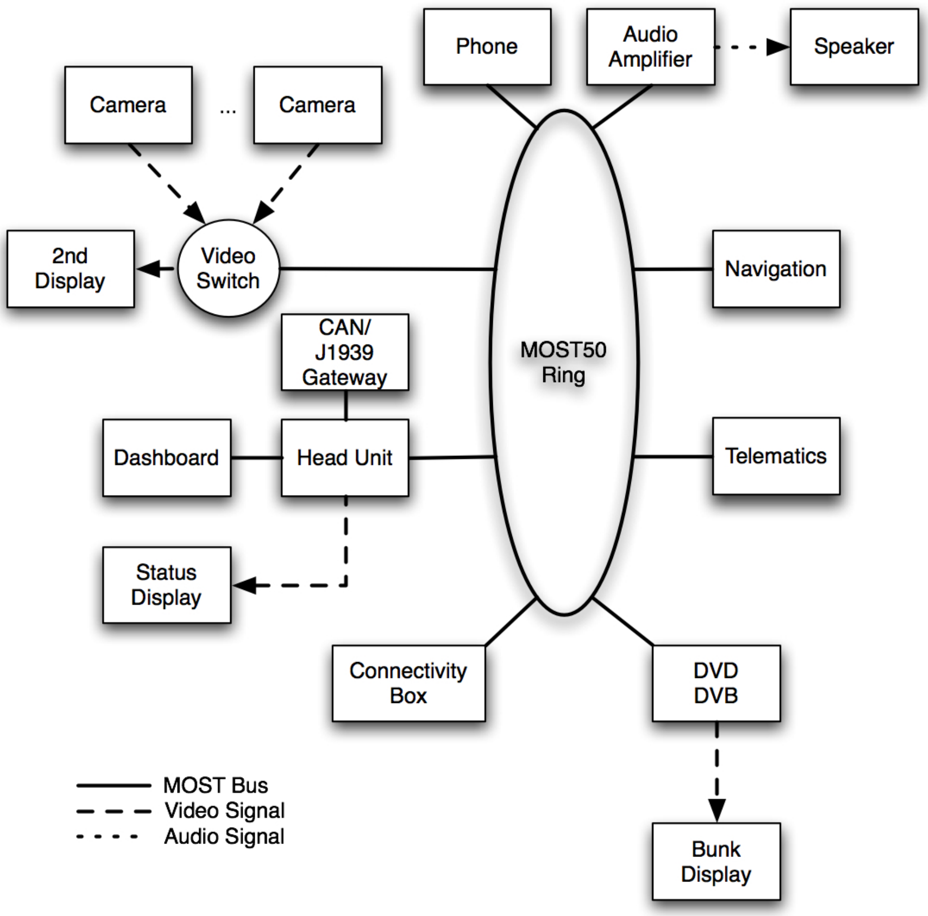

Figure 4.3: MOST50 Network

4.2.2 Related projects

MOST System is a widely used technology in today's car industry. MOST Network operating over an oPhy was implemented in more then 40 vehicle models of European top carmakers [33]. The leader of the ePhy development process is Toyota Motor Corporation. On the basis of the known facts, that the MOST50 meets the carmakers requirements sufficiently (i.e. double bandwidth and lower cost) and the switch from oPhy to the ePhy does not imply any application and framework changes [34]. Furthermore utilization of the system by carmakers in their new models is highly probable. Exceptions are carmakers with an already advanced implementation of MOST oPhy. Companies such as BMW or Daimler Chrysler do not want to lose their lead in the optical field area investigation and will probably continue to support further MOST oPhy versions such as MOST150.

4.2.3 Communication

In order to explain the communication process on the application layer, a more detailed example will be introduced and described. To keep the complexity of the example on an understandable level, let us consider a simple case from a Figure 4.4 with an audio, phone and HMI devices connected to the MOST50 bus. According to the most terminology, the FBlocks amplifier and GSM are called slaves and FBlock HMI is titled as a controller. The messages sent though the control channel are denoted as protocols. The communication example is shown in the Figure 4.4.

Example: *An audio device contains more function blocks i.e. CD player, amplifier*

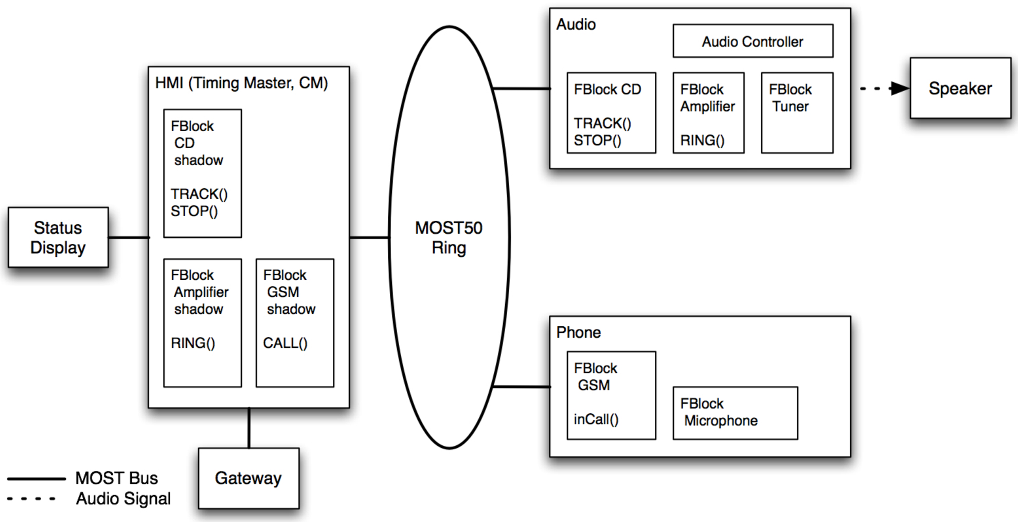

Figure 4.4: MOST Example

and radio tuner. After the change of the CD track, an incoming phone call will occur and the sound signal will be changed.
Solution: The HMI controls the Audio device via the FBlock CD shadow located in the controller. As mentioned in the chapter 2.1, the shadow in the controller represents an image of the property of the slave device. The next track on the CD can be chosen by pressing the NEXT button, where the shadow of the CD will transfer the following protocol from the HMI device (controller) to the amplifier (slave): **CD.1.Track.Set(2)**. On the application layer the physical addresses are not known, hence the Network services of HMI assigns to this protocol the device ID parameter as follows:

Audio.CD.1.Track.Set(2)

and for the transmission the structure is completed by a sender's address: **HMI.Audio.CD.1.Track.Set(2)**. This telegram is received by the audio device as a **HMI.CD.1.Track.Set(2)**, where the parameter device ID=Audio is missing, since there is no need to have this information on Audio's application level.
Following the same procedure a status reply can be sent:

Audio.HMI.CD.1.Track.Status(2),

similarly interpreted by the controller as: **Audio.CD.1.Track.Status(2)**. The content of the status message can be displayed on the monochrome Status Display (SD) . Until this point we do not have any synchronous or asynchronous channels allocated on the MOST bus. The only used communication channel is the control channel, because the amplifier and the speakers are integrated, connected to the audio device respectively.
Let us assume that the integrated GSM mobile unit is receiving a call. Thus after the reception of the call the synchronous channel has to be allocated. Firstly the user has to decide if the call will be accepted or rejected. The phone number can be displayed on the SD via this telegram:

GSM.HMI.1.Call.Status(PhoneNumber)

(where Call is an event) from GMS unit to the HMI device.
Simultaneously the properties **Audio.HMI.CD.1.Stop.Set()** in the CD and **Audio.HMI.Amplifier.1.Ring.set()** in the amplifier are started. The ring tone can be integrated as e.g. generated sound from synthesizer in amplifier, saved ring tone in HMI/Amplifier or different solution for integrated phone module. In the case of the acceptance a method **inCall.StartResult** provided in the FBlock GSM is triggered, otherwise when the call is not accepted the method **inCall.Abort** is started. Method **inCall.StartResult** will act as an initiator for establishing

a connection between the source and the sink. The Connection Manager (CM) is responsible for all synchronous connections. The procedure for a establishing connection is:

1. Firstly the initiator (inCall) starts a method BuildSyncConnection in the CM.

2. The connection Manager will establish and maintain the synchronous channel between the source (GSM unit) and the sink (Audio device), hence the CM will send a command to the source, to connect its output to the synchronous network channel. In this case, the source unit does not need to allocate the channel and uses the proposed one from CM. After this, the source unit sends a status reply to CM.

3. If the status is 'connected' the CM is trying to connect the sink to the same channel. After sending the description of the channel (delay and number), sink is connected and status reply is sent back. When the sink (i.e. the amplifier) is connected, the ring signal will be cancelled and the GSM sound signal can proceed to the speakers.

4. When source and sink are connected to the channel the connection is established and the report to the initiator (GSM unit) is sent. CM stores the connection data in case that new sink wants to connect to the source.

Now the telegram **inCall.Result** from the GSM to the HMI unit can be sent. Let's assume, that one FBlock in the GSM unit is a microphone connected to the GSM voice coder. The GSM call is finally established through the MOST Network.

4.2.4 Aspects

In this section is my solution analyzed with regard to the aspects described in the third part of the thesis.

- Cost - In order to analyze the cost of the system a trade off between the cost related to an introduction of new technology and the future sufficiency of the network has to be chosen. On one hand we have the expenses for the implementation of new protocol: particular devices need to be equipped with INIC for MOST50, new interfaces to connect the devices, NetServices functions and application layer have to be defined. On the other hand the future utilization of the network should be considered carefully (i.e. how long will be the network sufficient for the new devices and technologies?).

- Scalability - This proposal is designed as a fully scalable system. Firstly the MOST bus can operate with 64 INICs, hence we can connect up to 64 heterogeneous devices to the network and secondly the MOST Technology is scalable itself, since different MOST versions (MOST50, MOST150, etc.) can be connected to the INIC, without any changes in the higher layers.
- Variability - Different variants and combinations of multimedia devices are supported. From the simplest variant consisting of one audio device and integrated phone unit, till complex combination of multimedia devices (see Figure 4.3), the proposed network can be implemented.
- Dependability - Reliability, availability and safety are ensured by the properties of the MOST technology. Namely the error detection and the phase lock loop mechanisms are providing reliable services. Maintainability is considered in the system as well and further changes or improvements are available.
- Flexibility - Flexibility is ensured by the MOST Technology. Different topologies are possible and different physical layers for the MOST Technology are available. The change of the physical layer does not affect the higher layers.
- Standardization - MOST System is a de facto standardized network. Front automotive carmakers, which are the members of MOSTCO, are developing and improving the system.
- Compatibility - Compatibility is guaranteed with a gateway to the CAN-based network and with the connectivity box.
- Responsibility - Since the MOST System is an open standard, the implementation can be accomplished by automotive producer in conjunction with appropriate vendors. Thus the responsibility is derived from this cooperation.
- Bandwidth - Particular devices can use the bandwidth up to 50 MBit/s. For calculating the amount of bandwidth we have to consider the audio and video signal separately. The most bandwidth consuming audio device in the network is a DVD player using an AC3 codec with data rate 448 kBit/s, also known as a Dolby Digital. Enhanced AC3 codec in Digital TV has improved coding efficiency and the bandwidth needed is about 256 kBit/s. Video signal can be transferred over the MOST Network in compressed format. From Figure 4.3 results, that only video signal transferred over the network is a navigation video signal. This signal has to be compressed and the bandwidth depends on the implemented navigation device.

- QoS - The introduced priority levels ensure that the important messages will be sent, when for example the control channel is overloaded.

- Power Supply - The power supplies in the proposal have to be separate from the INICs, micro-controller and application peripherals.

- Packaging - The proposed solution is organized in a distributed manner (devices communicating over a shared bus). Theoretically any device in the MOST network can be a timing master, but in this case the HMIIOM is logically chosen as a control unit.

- Software strategy - Depending on the approach of carmakers different strategies can be used. For example the navigation device can send only GPS position data to the HMIIOM, where implemented software will draw the position as a picture. Other solution will be to have the software part in the Navigation GPS unit and send over the network the data in a viewable form (shown on the 2nd display).

- Feature expansion possibility - The extensive research process of MOST technology is giving us a certainty of further development of the system. Hence more compatible devices and functions will be available.

- Technology risks - With the introduction of a new technology there is certainly a risk present, even though the MOST Network is de facto standard.

4.2.5 Summary

MOST Technology is a dynamically developing area. In this part the description, related projects, communication example and aspects comparisons of the proposed solution were investigated. Table 4.1 shows how the particular aspects can be interpreted and how significant they are for this proposed solution. Among the others the importance of scalability and cost should be emphasized. MOST50 proposal appears to be as a promising solution for automotive multimedia networks. An example from the Section 4.2.3 is described by MSC (Message Sequence Chart) in Appendix A.

4.3 Network based on IDB-1394

4.3.1 Description

Although most car manufacturers focus on MOST as the favorite network, a great deal of research on how to implement a IDB-1394-based network has been done. The approach was in most cases an academic one. As mentioned earlier in this report, companies, such as Renault or Nissan have already implemented an advanced prototype of an IDB-1394-based network. This topology is shown in Figure 4.5. The most bandwidth-consuming devices are the cameras and the entertainment sources. As DVD and DVB are assumed to be available only during rest times, their impact on the bandwidth is moderate. The proposed topology includes on the other hand a large number of cameras which send video data all the time. Therefore it makes sense to put the cameras on a separate subnet and let the head unit act as bridge.

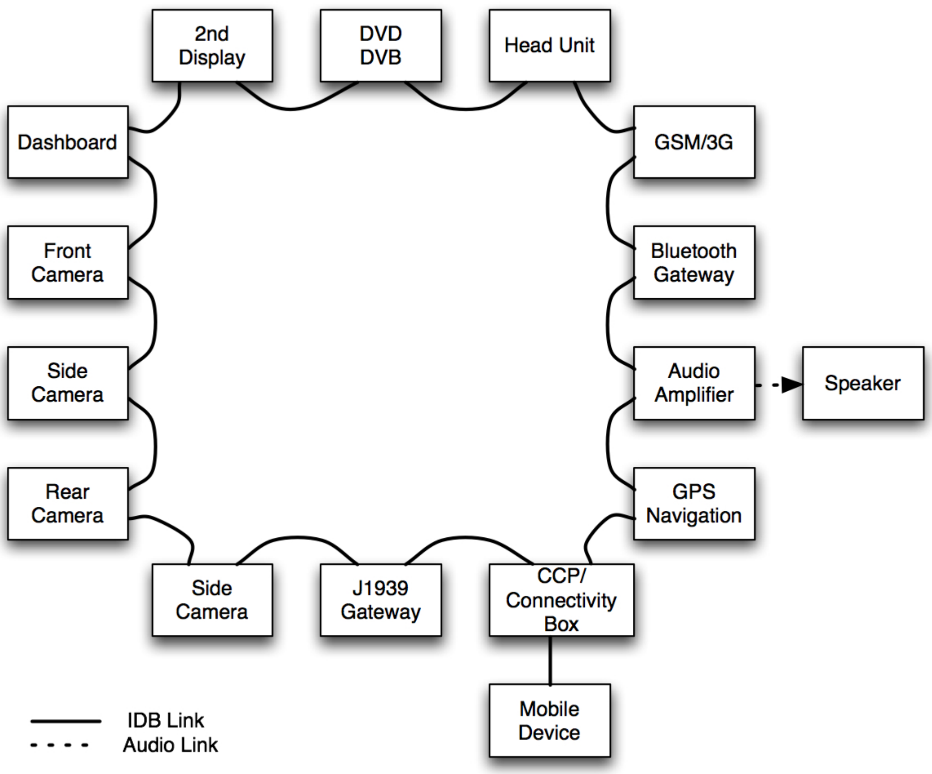

Figure 4.5: Topology of the proposed IDB-1394 network

4.3.2 Aspects

- Cost - As IDB-1394 only specifies an optical physical layer based on POF or PCS, cost may be rated as high due to the optical fibers on one side and the necessary optical-to-electrical and electrical-to-optical converters on the other side.

- Scalability - The IDB-1394 network is able to reconfigure itself fully automatically. Although the topology of a typical automotive network is more or less static, the reconfiguration plays an important roll if a device is connected to the CCP.

- Variability - This network has the potential to be the most variable and flexible network mentioned in this report, due to the origin in the Firewire protocol. Starting from two devices which are able to configure themselves, up to 63 nodes may be integrated.

- Dependability - Firewire was developed to support a physical star, tree or daisy-chain topology. The automotive version also allows a ring which provides an alternative route if the connection between two nodes breaks down due to whatever reason.

- Standardization - IDB-1394 is fully standardized by the IDB forum as well as AMI-C

- Compatibility - IDB-1394 is completely compatible with IEEE-1394-based consumer electronics as most protocol layers are equal. Furthermore gateways to Bluetooth and CAN are available.

- Bandwidth - Compared to MOST the bandwidth is much higher. As long as compressed video is used there will be no limitation. On the other hand when uncompressed data is needed because only minimum delay can be accepted, it turns out that the available 400 Mbit/s may be the bottleneck depending on resolution, colourdepth and frames per second.

- QoS - IDB-1394 supports both asynchronous and isochronous traffic and provides mechanisms for QoS as mentioned earlier.

- Power Supply - Traditional IEEE-1394 is able to supply power to the devices using some of the copper wires. As the automotive version is only specified for optical fibers, extra wiring is needed.

- Technology risks - As can be seen in the related projects section, there has been a great deal of research done using this type of network but most car manufacturers focus on the MOST solution. Therefore it is hard to say, how the support for this technology will be in the future. Also the latest update of the official IDB website dates back a rather long time.

4.3.3 Summary

A major benefit of the IDB-1394-based network is the dynamic reconfiguration after booting and after changes in the topology, such as connecting a portable device to the consumer convenience port. If different encoding is used, as mentioned in the Nissan project in the related work section, IDB-1394 is even suitable for camera applications where no delay can be accepted. The drawback nevertheless is that currently only optical fibers are specified for automotive applications which makes it interesting for luxury cars due to the rather high costs of fibers and converters.

4.4 Network using the APIX link

4.4.1 Description

Figure 4.6 shows a proposed topology with a focus on the APIX link. A similar network for the entertainment system in a car is shown in [28] and [31]. The network consists of the head unit, which contains most of the intelligence, two or more displays, cameras located around the vehicle and gateways to the J1939 vehicle bus, GPS and GSM. All cameras are assumed to have a resolution of 640x480 pixels operating at 60 frames per second. If the cameras have a color resolution of 16 bit, or 10 bit for the night vision camera respectively, the bandwidth of the APIX link will be sufficient to transmit the multiplexed uncompressed signal.

$$Bitrate = \Sigma_{sources} resolution * colordepth * frames\_per\_second$$

On the other hand, there is no bandwidth problem at all with the two rear view cameras and the other sources such as the DVD player or the DVB receiver. The two camera signals can even have a colour resolution of 24 bit and the data rate of the multiplexed signal is still below 1 GBit/s. As DVD and DVB are not available during driving, those sources are connected via a video switch, therefore they have no impact on the bandwidth calculation.

One advantage of this link is that the cameras can be supplied with power over the return channel, due to the fact that both the uplink and the downlink channel are completely decoupled from direct voltage. Therefore there is only need for one STP cable to connect the camera and the head unit.

As the side-band channels can be used to control the cameras in real-time by transmitting the I^2C as well as the CAN bus, it is also possible to synchronize them in order to get a 360-degree-view or a multiview system.

4.4.2 Communication

Front camera system: The front and side cameras send uncompressed video via multiplexer to the CPU in the head unit. In the CPU of the head unit all the necessary image processing is done which is required for the lane departure warning system, object recognition and similar tasks.

Rear view cameras and entertainment sources: As the DVD, DVB and other entertainment functions are not provided during driving, a video switch is suggested

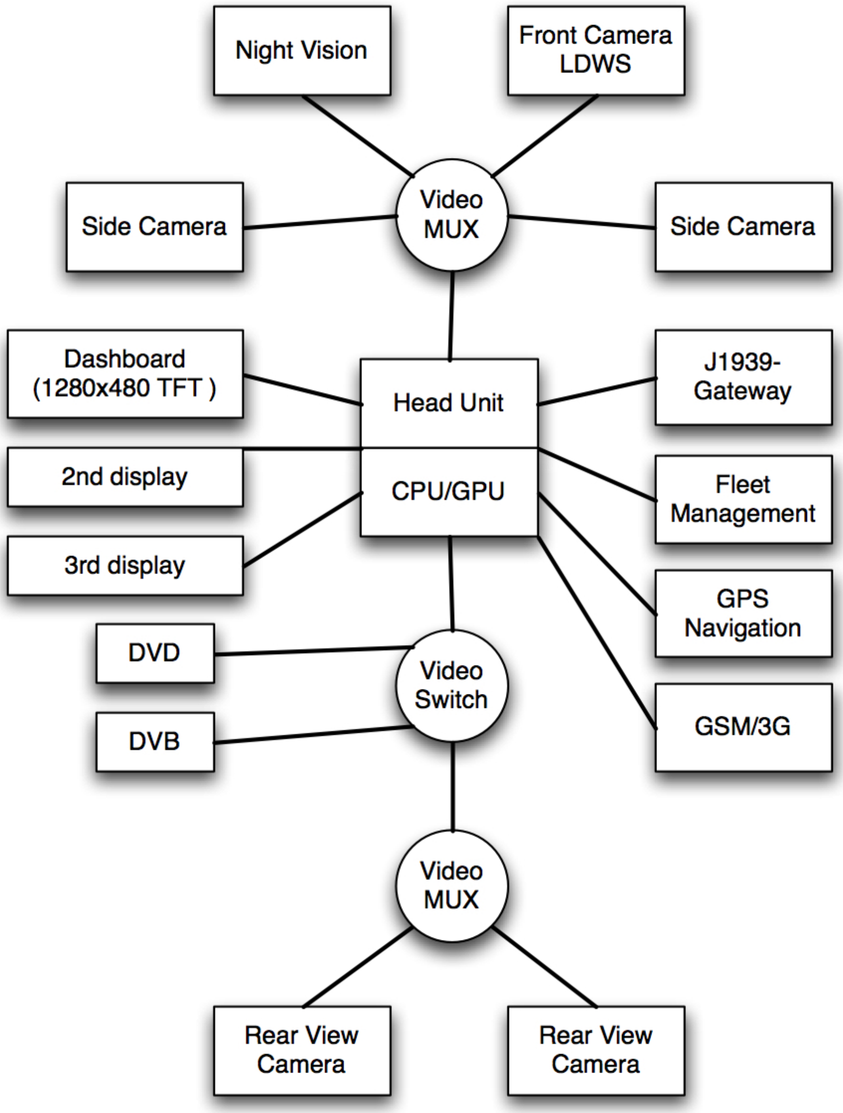

Figure 4.6: Topology based on the APIX link

to switch video between the rear view system in normal operation and DVD/DVB during the rest times.

Displays: As mentioned before, the displays receive uncompressed pixeldata from the head unit. To input data, such as messages from the driver to the dispatcher, touchscreen can be used. The emerging control data can be transmitted either by sending I^2C signals, by using modified CAN/J1939 frames or even by using the messages of the MOST control channel on the side-band channels.

GPS and Navigation: The communication between head unit and the navigation system works the same way as from the head units to the displays. The position is transmitted over the side-band channel and the according images, if not created in the head unit, will use the high-bandwidth link.

GSM and 3G: Communication with the world outside is important if a fleet management system is used, for the eCall system and for lots of other applications. Two different possibilities are imaginable here.

- Bluetooth - A Bluetooth tranceiver is integrated in the head unit or connected by a bus. In this case the communication will be done with an external GSM transceiver, such as a Bluetooth-enabled mobile phone.
- Wired - The GSM can also be integrated in the head unit or the integration can be achieved by transmitting data between GSM and head unit. As no high bandwidth is needed in the latter case, it can be done by the CAN/J1939 bus.

Audio: To transmit the audio signals between the devices, [28] and [31] propose a separate MOST ring. As the side-band channels of the APIX link provide almost the same bandwidth as the traditional MOST25 network it is also imaginable that sound could be sent over those channels. Further investigations can be done in this case.

4.4.3 Aspects

The following describes how the solution based on the APIX link performs in relation to the previously defined aspects.

- Cost - The use of shielded twisted pair cables instead of optical fibers keeps the cost of the solution low. On the other hand rather high development costs may arise as there is no real reference implementation available yet.

- Scalability - The Apix link is a point-to-point pixel link. Therefore the main limitations for the scalability are located in the head unit. The more connectors and the faster the CPU or GPU is, the more devices can be connected. Nevertheless the scalability is high.
- Variability - This link only makes sense if high-quality video is required. But then everything is possible, starting from a simple rear-view camera to a fully equipped network as proposed above.
- Flexibility - The GBit/s downstream link is a direct pixel link, but the side-band channels make APIX very flexible, as a variety of buses and protocols can be sent over those channels.
- Standardization - The APIX chip is solely developed and produced by the company Inova Semiconductors. A data sheet is available for download, but it is not standardized. On the other hand, a separate standardized MOST ring to transmit audio signals is suggested by Inova.
- Compatibility - The chip connects to common 10, 12, 18 and 24-bit RGB interfaces. Furthermore the side-band channels can transmit the popular I^2C bus bi-directionally to control camera functions.
- Bandwidth - Besides IDB-1394 (under certain conditions) this link is the only possibility in the automotive area to transmit uncompressed, low-delay video signals. Furthermore it is the only solution presented in this report which provides enough bandwidth for future high-resolution 1280x480 pixel TFTs which will probably replace the traditional analogue gauges.
- QoS - The control messages on the side-band channels do not influence the actual pixel data in any way. Consequently full QoS is given concerning the link itself.
- Power Supply - Devices such as cameras can be sourced by the same STP cable that carries the data. Therefore no extra wiring is needed.
- Packaging - The network consists basically of the central head unit and a number devices like cameras and screens which are connected directly or via a multiplexer to the head unit.
- Technology risks - As the APIX link was recently introduced in 2006 it is hard to say how it will be accepted by the very conservative vehicle industry. Although the technology is promising, the technology risk must be rated as high.

4.4.4 Summary

The APIX chip was introduced recently, but it has, as well as similar technologies from other companies, the potential to be implemented in a wide area. In particular if uncompressed video is required, for instance for object recognition, this link is the only one discussed in this report, which provides sufficient bandwidth. This applies also for a high-resolution digital dashboard replacement, which may be introduced in cars in a few years.

4.5 Comparison of the Proposed Networks

Particular solutions and their aspects are compared in this chapter. Table 4.1 shows how the aspects of the particular solutions can be depicted and how the proposals are related to each other. The numerical values assigned to the particular aspects are determined according to my own consideration and opinion on the proposals, based on the available informations and experiences from the automotive industry. The evaluation was accomplished as follows: one is the worst case and ten is the best case.

Aspects	*CAN*	*MOST50*	*APIX*	*IDB-1394*
Cost	7	6	5	4
Scalability	6	10	6	10
Variability	7	10	5	10
Dependability	10	10	10	10
Flexibility	4	10	5	10
Standardization	10	10	3	10
Compatibility	10	7	6	10
Responsibility	10	6	5	6
QoS	10	10	10	10
Bandwidth	10	6	10	8
Power Supply	5	5	9	5
Packaging	10	10	7	10
Software Strategy	10	10	10	10
Feature Expansion	5	10	5	10
Technology Risks	7	7	3	4

Table 4.1: Aspects of the particular solutions compared to each other

A suitable solution can be found, when particular requirements are defined and when the priorities of aspects are well known. By using the Table 4.1 such an outcome can be derived and the solution can be chosen. Generally a universal solution is impossible to define, since all of solutions have their own advantages and disadvantages and before the decision process, the requirements have to be defined.

By comparing the particular networks we can observe the following relations. Cost depends on many aspects, for example the cheapest solution is the CAN Network, but as it was stated it suffers from insufficiency in scalability, flexibility and feature expansion possibility. IDB-1394 network has a relatively high ranking in most of the aspects except the cost, which is caused by the optical physical layer. As it is visible from the Table 4.1 such an expensive solution should be evaluated, since it fulfills the other requirements and brings another benefits (e.g. future utilization of the system). The APIX link compared to the others is a promising solution for the transmission of video signals. Another important aspect is scalability, where MOST and IDB1394 networks indicate a full satisfaction. Aspects like dependability and software strategy are not dependent only on the used technology but also on the agreement between suppliers and automotive producers. Feature expansion possibility is an important property of the system and is fully satisfied in the MOST and IDB1394 technologies. Standardization is fulfilled in the CAN, MOST and IDB1394.

From my point of view the MOST Network for the audio signals and the APIX link as a medium for the video signals transfer appear to be as the most suitable solution.

CONCLUSIONS

Multimedia networks for automotive applications is an evolving and promising area. Researchers from different communities (such as IT, Communication and Electronic, etc.) are more focused on the automotive industry, in order to migrate their high-end products in to the vehicles. This naturally demands a new attitude towards new environment and conditions for their products. Besides this, the customers demand more sophisticated functions to be implemented in their vehicles. The car industry is the main driver for automotive multimedia networks and during the investigation was the car industry likewise the main source of information.

This thesis analyzes multimedia networks for automotive applications. The first part, introduction and related projects, introduces the area of investigation. In the second part an extensive survey about the state of art is given. The available communication protocols and technologies are described in detail. It should be remarked, that the development process is relatively young and the effort to standardize and propagate particular technologies is visible. The third part describes the requirements on the automotive electronics in general and requirements driven by infotainment systems. From the description of the aspects an outlook on the environment, where the final proposals should be implemented, is given. Finally the last part represents the goal of my thesis. By comparing the available protocols and networks with the investigated aspects four possible solutions are described and examined. The chosen topologies result from the network specifications and their implementation in the automotive industry.

Indeed the MOST Network is considered as a standardized and promising technology, but this does not mean that the importance of other protocols and networks should be decreased. CAN-based solutions can not support the development process for long time and will not prove satisfactory for the future devices. New networks and technologies supporting more bandwidth for video signals are going to be introduced in the future, but before this an APIX solution for video signals together with the MOST audio network appear to be, from my point of view, as the most suitable solution. An example of how the optical fibers can be used in the car is given in the IDB-1394 Network. Generally, the optical fibers are not popular among the vehicle manufacturers. This might be a disadvantages for the future technologies, when for example the bandwidth of copper cable will not be sufficient anymore, then optic fibers will be introduced. The disadvantage is the introduction of the optic fibers as a new technology into the already existing networks, without any previous experiences and implementations. On the other hand there is a huge development process behind the electrical cables and the methods, how to implement them in the automotive industry are well known.

My aim was to define the problems and aspects for choosing the automotive multimedia network. My suggestions for the decision process are correlated to the requirements of the automotive manufacturer. In other words they depends on what the manufacturer wants to implement. Its requirements are represented as the particular aspect ranking for each solution. Hence from the Table 4.1 can be this solution chosen, depending on the requirements. Generally a solution which fully satisfies all of the requirements does not exist and therefore a suitable trade off has to be chosen. A reasonable approach, when the decision should be done, is to consider the network usage from the future point of view and to take into the account all protocols and networks available on the market. Newly arising promising technologies should be considered as well.

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LIST OF ACRONYMS

ACK/NAK Acknowledge/No Acknowledge: Indicates that a message was or was not received correctly

BER Bit Error Rate: is the ratio between the number of bits which were transmitted incorrectly and the total amound of bits transmitted.

CAN Controller Area Network: Most common field bus to connect the ECUs in todays vehicles.

CCP Consumer Convenience Port.

DVB-T Digital Video Broadcasting Terrestrial: Standard for digital TV.

d2B Domestic Digital Bus: An early multimedia network for vehicles based on an optical physical layer.

DTCP Digital Transmission Content Protection.

EBS Electonic Brake System.

ECU Electronic Control Unit: A microprocessor which controls certain functions in a vehicle.

GPS Global Positioning System.

HMI Human Machine Interface.

LIN Local Interconnect Network: A low-cost low-speed in vehicle network, used for sensor and actuators.

MCS Message Sequence Chart.

PCS or HCS Polymer/Hard Clad Silica.

POF Plastic Optical Fiber.

S/PDIF Sony Phllips Digital Interface Format.

VCSEL Vertical Cavity Surface Emitting Laser.

RDS Radio Data System.

PLL Phase-locked Loop.

LIST OF APPENDIX

APPENDIX A: MESSAGE SEQUENCE CHARTS - AN EXAMPLE

A.1.1 MSC Introduction

Message Sequence Charts (MSCs) are used to describe behaviour of the distributed in-vehicle multimedia networks [35]. MSCs are standardized by ITU (International Telecommunications Union) and are closely related to the model based SDL (Specification Description Language). Two different groups of MSCs were defined: High Level MSCs and basic MSCs. In this Appendix we will deal only with basic MSCs where conditions, timers, errors and messages are used to ensure and predict the behaviour of distributed telematics and infotainment systems. The following Figure A.7 shows, which blocks are used in example A.1.2 and how the MSC can be adopted to the in-vehicle infotainment and telematics systems. This brief overview is only as an introduction for the following example and should not be comprehend as a MSCs description. More information about MSCs can be found in [35, 36].

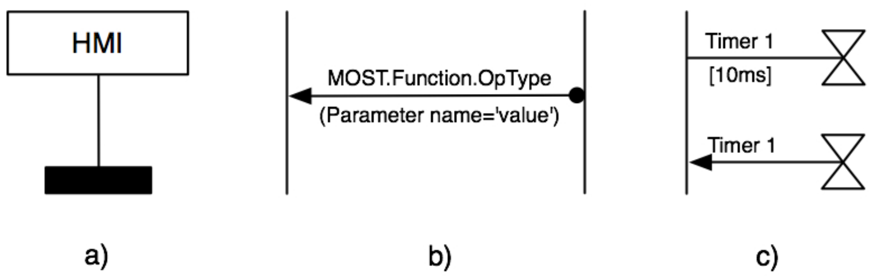

Figure A.7: Adaptation of MSCs for Automotive Multimedia Networks: a) General instance for user interaction b) MSCs message c) Timer (set and timeout)

A.1.2 MSC Example

Description In this paragraph the example from section 4.2.3 is described by MSCs. Hence the protocols sent through the communication bus are taken from the MOST FunctionBlocks Catalogs (e.g. MOST FunctionBlock Audio Disk Player [37], MOST FunctionBlock Amplifier [38], etc.) and vary from the used protocols in the example 4.2.3. The reason for this consists in the simplicity and comprehensibility of the previous example. It should be noted, that the meaning of these protocols remain unchanged. Figure A.8 shows the MSCs diagram for the example. In this example the HMI and the Head Unit are represented as one instance. Protocols

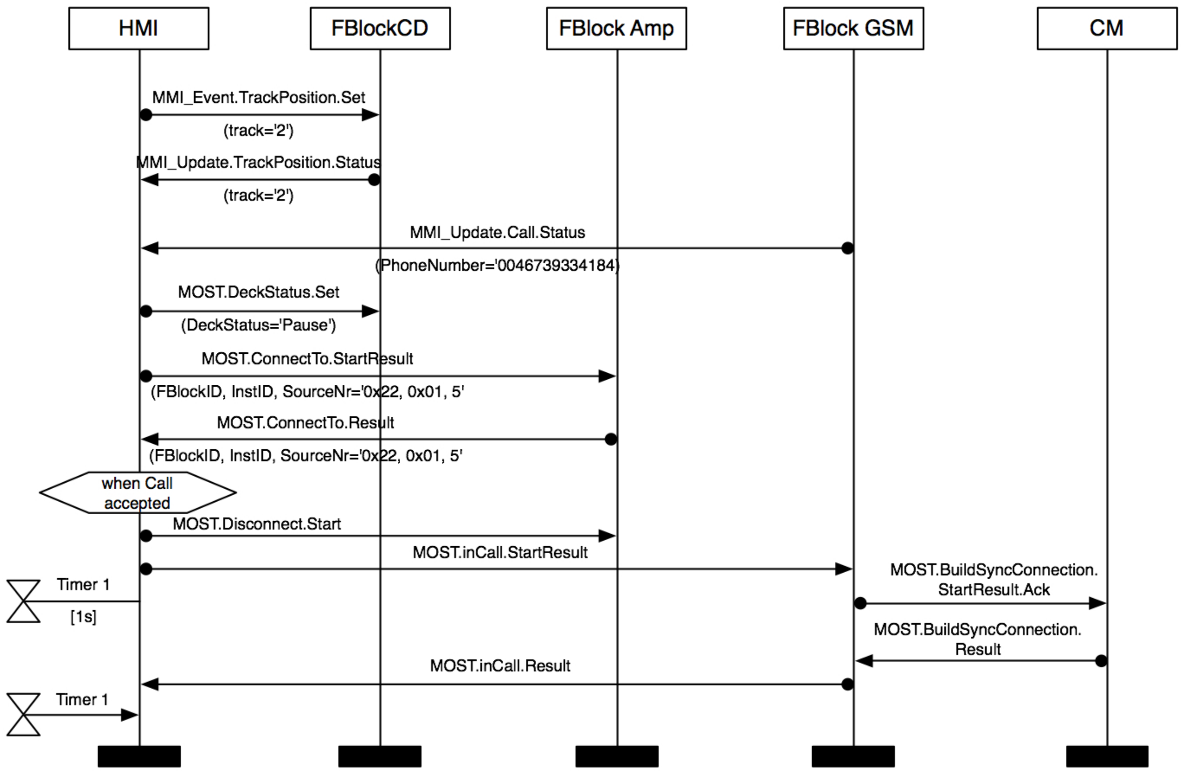

Figure A.8: An example from section 4.2.3 described by MSCs

beginning with the preamble MMI, are dedicated messages for the interaction with HMI interface (update end event). The ring tone is stored in the head unit device and is connected to the amplifier by using the function Connect. To keep the complexity of this example low, the amplifier is directly connected to the synchronous channel with the ring tone signal, without any preceding allocation of this channel. The MSCs diagram is created according to the available specifications for the particular devices. At the time of writing the MOST Function Block Catalog for the phone unit is not available.