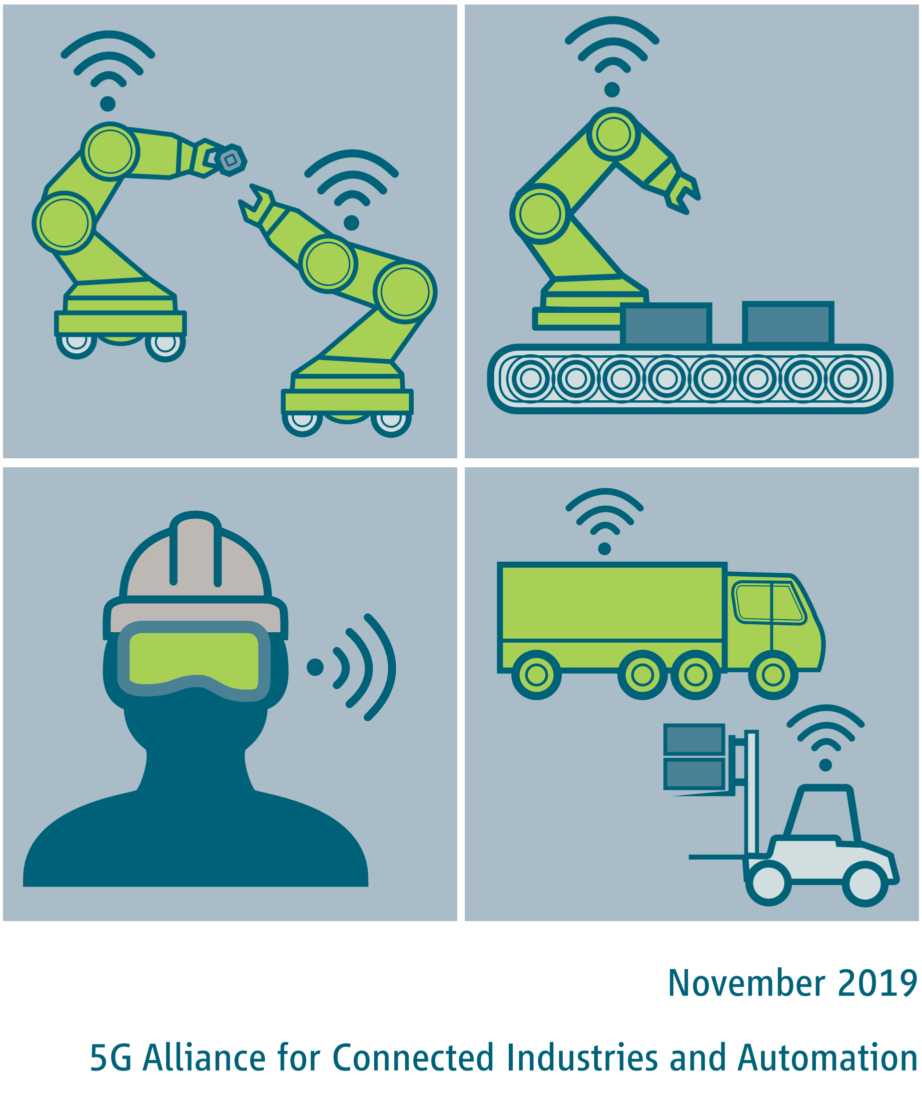
5G ACIA
5G Alliance for Connected Industries and Automation

White Paper

A 5G Traffic Model for Industrial Use Cases



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5G Traffic Model for Industrial Use Cases

Contact:
Email: info@5g-acia.org
www.5g-acia.org

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Contents

1 Abstract

Applications in industrial automation systems have stringent requirements regarding latency and reliability. These requirements are already met by current communication systems, mostly based on wired technologies. To determine whether a wired system can be replaced by a wireless 5G system or not, it is necessary to analyze the actual data volumes and traffic types of industrial use cases. To accurately predict network load, a realistic traffic model is required to enable performance evaluation and design of the corresponding communications systems. The communication requirements of selected use cases must therefore be analyzed, modelled and validated.

This white paper describes a 5G user data traffic model for industrial use cases employing a 3GPP-compliant radio network. The traffic is modelled by a set of parameters relevant to the design and dimensioning of 5G networks.

These traffic model parameters give both network service providers (SPs) and network service users/operational technology (OT) companies to a common method of describing the projected 5G traffic. Based on these mutually agreed parameters, SPs can assess and install necessary spectrum and network resources for the 5G networks offered to OT companies.
The traffic model will focus on use case categories of high priority for industrial automation, process automation and inbound (production) logistics.

2 Terms and definitions

This is a list of the most important terms and definitions used in this white paper.
- Where not otherwise indicated, definitions are from 5G-ACIA
- Some are based on existing definitions but slightly amended by 5G-ACIA, i.e. for greater clarity. This is indicated accordingly, and the source of the underlying definition is given
- Direct citations are in italics and parentheses, and the source is given
- Where a term is defined in detail later in this white paper, reference is simply made to the corresponding section

2.1 Local application function

Hardware and/or software of a device that is a local element of a distributed application.

2.2 Communication function

Hardware and software of a device that implements the communication stack and reference interface.

2.3 Service access point and logical endpoints

The service access point (SAP) allows user data to be exchanged between a local application function and a communication function.

The SAP uses logical endpoints within the communication function, namely a logical source endpoint (LSEP), via which the local application function sends data to the communication function, and a logical target endpoint (LTEP), via which the local application function receives data from the communication function.

The LSEP and LTEP may have differing communication characteristics, e.g. with respect to data volumes, latency, etc.

Within a radio network, the LSEP and LTEP can be mapped to radio up- and down-link data transmission, respectively.

2.4 Logical link

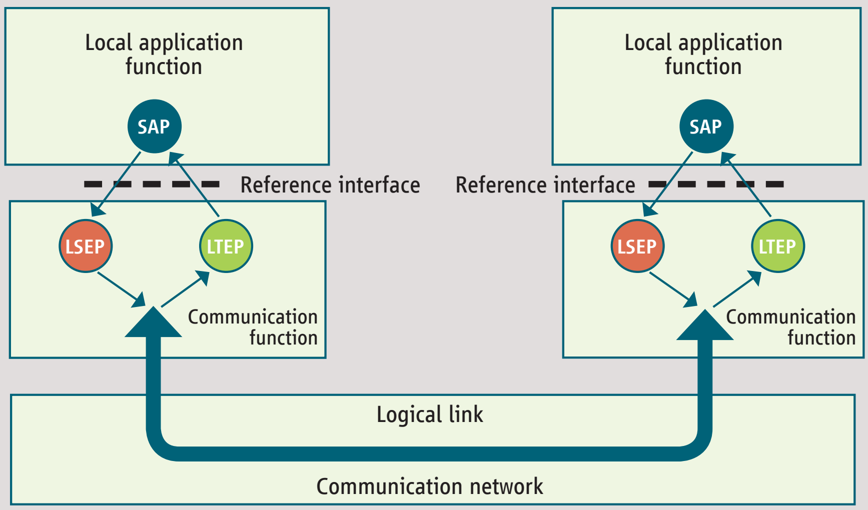
According to IEC 62657, a logical link is an: "Application oriented communication relationship which enables the transmission of user data between one logical end point of the reference interface in a source device and one logical end point of the reference interface in a target device". (Source: IEC 62657 4, 3.1.2)
A logical link comprises a pair of SAPs that communicate with each other, as depicted in Figure 1.

2.5 Reference interface

The reference interface is the exposed interface between the local application function and the communication function. In the case of a 5G network, the communication function can be implemented in a UE or in a network node. The reference interface is the interface between the UE or the wired network node on the one side and the application functions on the other; its actual implementation is manufacturer-dependent (AT commands, PCIe, USB, serial i/f, etc).

A reference interface can include more than one SAP, and/or more than one source and/or target logical endpoint.

Fig. 1: Reference interface and logical link



Source: 5G-ACIA / ZVEI

3 Use cases and traffic types

The most important use cases with their varying demands on the communications network have been prioritized and described in [1] 3GPP TS 22.104 Annex 2. This traffic model addresses the use cases encountered in factory and process automation, human-machine interfaces and production IT, logistics and warehousing, and monitoring and maintenance. However, due to the generic nature of the traffic model, it can also be employed to describe and quantify traffic patterns of use cases applicable to other vertical domains such as rail-bound mass traffic and electric power distribution and central power generation.
Use cases explicitly addressed by this white paper:

- Motion control
- Control-to-control communication
- Mobile control panels with functional safety applications
- Control-to-sensor/actuator communications
- Mobile robots and automated guided vehicles (AGVs)
- Remote access and maintenance
- Augmented reality
- Closed-loop process control
- Process monitoring
- Plant asset management

These use cases display diverse traffic behavior, ranging from periodically generated messages with small data volumes to aperiodic messages with, in some instances, very large data volumes. This section describes the data traffic types characteristic of industrial use cases. These traffic types are employed as the basis for defining parameters that describe a traffic model applicable to all use cases given above.

The parameters that describe the traffic model are defined and detailed in section 5 below.

3.1 Deterministic periodic traffic

Messages for automation control loops and process control use cases are typically deterministic periodic traffic.

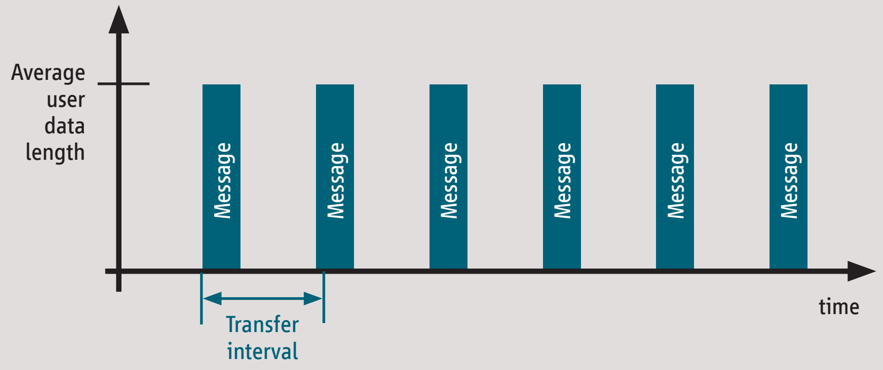
Applications with this traffic type send messages at defined time intervals. These applications also expect to receive messages with predictable latency at the same defined transfer intervals. Acceptable latency and tolerable latency jitter depend on the particular application and use case, and are not described by the traffic model given in this white paper.

Deterministic periodic traffic can be specified using the parameters of message size and transfer interval.

A subset of this traffic type is deterministic time-triggered traffic. This can occur when local instances of a distributed application function do not have synchronized clocks. If the local instances of the distributed applications share a global clock time, deterministic time-triggered traffic of high precision is not required.

Deterministic time triggered traffic can also be specified using the parameters of message sizeand transfer interval. Therefore, from a traffic model viewpoint these parameters do not differ from those of the generic deterministic periodic traffic type. A graphical representation of this traffic type is given below.

Fig. 2: Periodic traffic



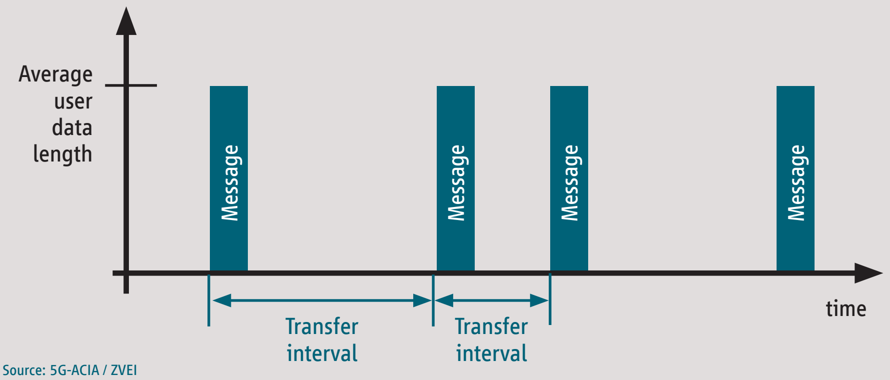
Source: 5G-ACIA / ZVEI

Sizes of messages for a local application function may vary depending on the particular use case. Moreover, the transfer interval may vary, especially for deterministic time triggered traffic. For the sake of simplicity, these variations are not considered in the present traffic model. However, for more detailed simulation of network behavior such variance may be of importance. Deterministic aperiodic traffic is own section i.e. 3.2

Messages generated e.g. by process events are typically deterministic aperiodic. This traffic type consists of messages that are sent regularly but aperiodically, i.e. there is no defined transfer interval between messages.

Deterministic aperiodic traffic can be specified using the parameters of message size and transfer interval, whereas the transfer interval is an average value and not a defined value as for deterministic periodic traffic. Below is a graphical representation of this traffic type with messages of average size sent by an application regularly but not with a constant transfer interval.

Fig. 3: Aperiodic traffic



Source: 5G-ACIA / ZVEI

Similar to deterministic periodic traffic, message size may vary.

More detailed modeling of the statistical variation of this attribute may be needed for e.g. simulations and detailed evaluations.

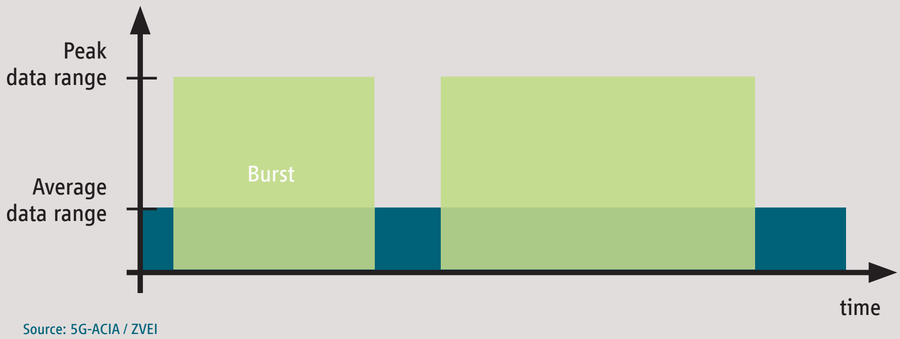
3.2 Non-deterministic traffic and burst traffic

Non-deterministic traffic can be periodic or aperiodic. Messages of this traffic type are not expected to be received at the target endpoint within a specified time frame (transmission time) or within a specified time period between two consecutive messages (update time). The minimum requirement is that messages are correctly received and in the correct order.

Burst traffic is characterized by a sequence of successive messages that are sent in a "burst", for example to transmit images. Bursts can be periodic or aperiodic. Burst messages are not expected to be received at the target endpoint within a specified time frame (transmission time).

Non-deterministic and burst traffic can be specified using the parameters of average data rate and peak data rate. A graphical representation of this traffic type is given below.

Fig. 4: Non-deterministic traffic



Source: 5G-ACIA / ZVEI

3.3 Traffic types and usage examples

In the table below there are some example use cases extracted from TS 22.104 for each of the above described traffic types.

Table 1: Traffic pattern types

Traffic type	Example
Deterministic traffic	
Periodic and time-triggered periodic	Sensor-to-controller messages sent periodically between synchronized, time-sensitive applications. For example a pressure sensor sending values to a machine PLC, or emergency stop signals from hand-held controllers being sent to a machine PLC. Controller-to-actuator messages sent periodically, e.g. a PLC sends commands to a motor drive.
Aperiodic	Sensor-to-controller messages sent e.g. on detected status changes or value changes between non-synchronized, time-sensitive, applications. for example, an optical sensor sending positional information to a conveyor belt PLC. Controller-to-actuator messages sent aperiodically, e.g. a light curtain PLC sending a stop command to a mobile robot
Non-deterministic and burst traffic	
Periodic	Client/server traffic between non-synchronized, non-latency-critical applications, e.g. high-resolution cameras sending images to a pattern recognition server.
Aperiodic	Client/server traffic with non-latency-critical characteristics, e.g. software updates, test report uploads, screwdriver torque documentation, etc.

Source: 5G-ACIA / ZVEI

It should be noted that there are a range of other communication parameters, such as service reliability, service availability, latency and latency jitter, that are of crucial importance to many use cases as outlined in [1]. However, these characteristics are not covered by this traffic model. They are determined by the implemented network technology, by the quantity of deployed (dedicated) resources and by the radio access network (RAN) design.

4 Reference interface when applied to 5G networks

4.1 Multiple application functions

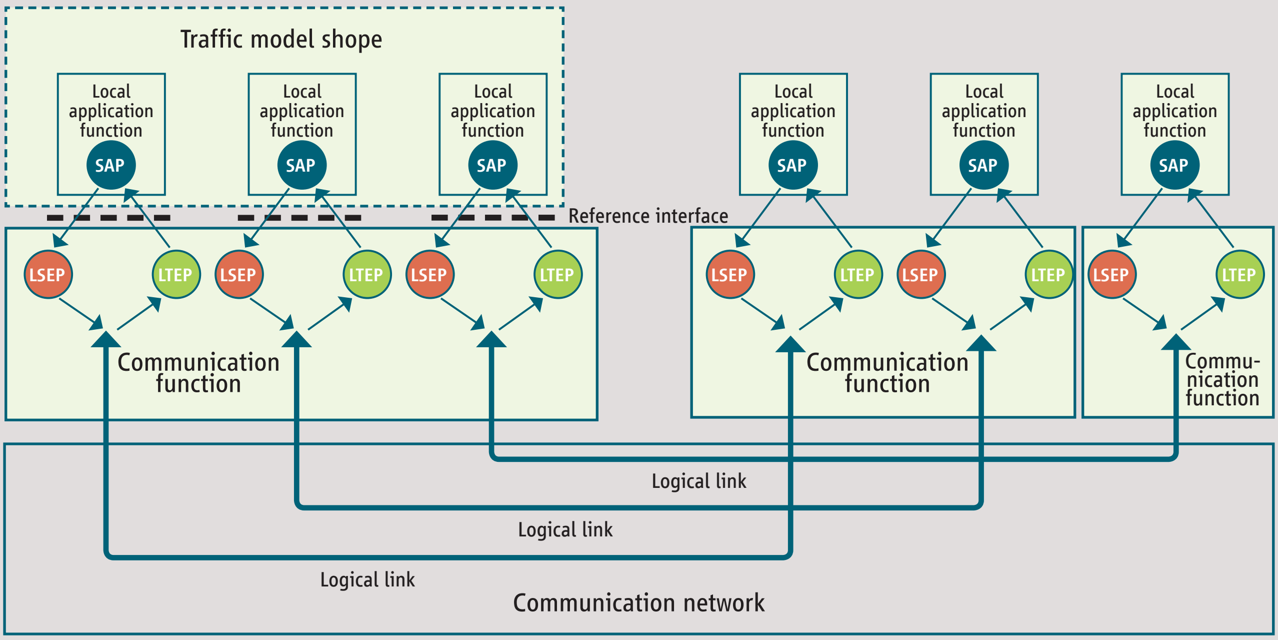
The traffic model defined in this white paper defines and describes the traffic as observed at the reference interface of each local application function. There may be multiple local application functions interfacing with a single communication function; the local application function may also have more than one SAP (depending on how the function is implemented).

A communication function can act as an I/O gateway that aggregates traffic from multiple local application functions; these local application functions operate independently of each other and will, in most cases, have differing traffic types. Therefore, the traffic for each local application function must be modelled separately. When the communication function aggregates traffic from multiple applications, all logical links will be transmitted across the 5G network via one or several concurrent radio connections. Whether one or more radio connections are used depends on the communication function's (i.e. a UE or a network node) capabilities and on configuration parameters.

Figure 5 below depicts a deployment scenario where (left-hand side) three local application functions interface with a single communication function. Each local application function communicates with a peer application function at the remote end (right-hand side) via a logical link. At the remote end, two local application functions interface with a shared communication function, while the third one interfaces with a communication function of its own. The remote communication functions are in most cases wired network nodes that reside outside of the 5G network.

As depicted in Figure 5, this traffic model only describes reference interfaces for communication functions that are UEs. Wired terminals do not contribute to radio traffic and are therefore not relevant to this model.

Figure 5: Deployment of logical application functions



Source: 5G-ACIA / ZVEI

Only those local application functions and reference interfaces are of relevance to this traffic model that interface with a UE-type communication function. When a communication function is not a UE (i.e. it has no radio interface) if will not contribute to radio traffic, and therefore has no relevance to the traffic modeled and observed within a 5G network.

All messages sent from the LSEP and/or received from the LTEP are transmitted via the reference interface to/from the communication function, which relays the traffic via the communications network to its destination. The communication function will add some overhead from the 5G network protocol stack (see 3GPP 23.501). For this reason message sizes and the quantity of messages observed at lower layers in the 5G network may be significantly larger than those seen at the reference interface.

Messages at the reference interface can have L2 Ethernet or L3 IP frame structures – in both cases, message sizes referred to in this traffic model include the protocol overhead imposed by Ethernet and/or IP headers.

4.2 Communication methods

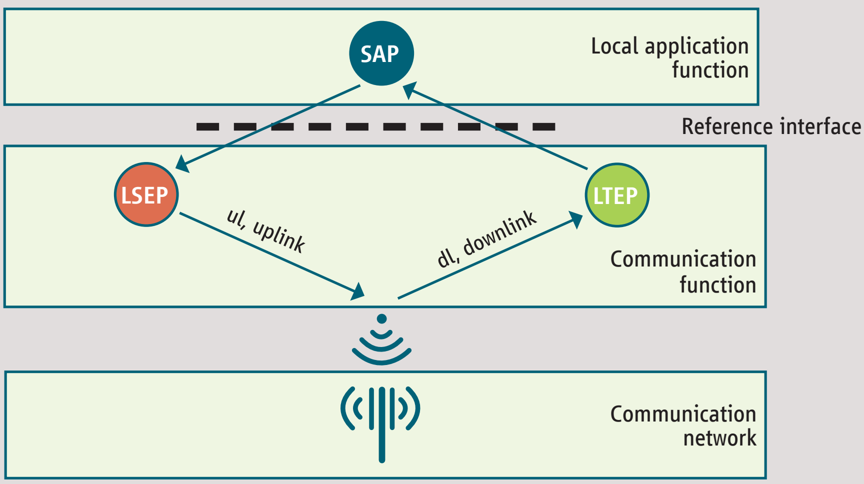
Logical links between application functions can be implemented by means of various communication paths and methods available within a 5G network:

- Point-to-point (P2P): a message has a unique destination/source address and is transmitted over the communications network
- Device-to-device (D2D): a message has a unique destination/source address and is transmitted directly from one device to another device, not via the communications network; the communication functions have a direct radio connection.
- Point-to-multipoint (P2M): a message has a unique source address, while the destination is a multicast or broadcast address. Multipoint messages are broadcast by the radio network and therefore applicable for LTEP, i.e. for DL direction only.

4.3 Radio communication direction

A further 5G network-related communication characteristic of paramount importance is whether messages are sent or received, i.e. whether they are sent via uplink (UL), from the UE to the network, or via downlink (DL), from the network to the UE (see Figure 6 below). Messages sent by a LSEP are transmitted via the UE uplink, while messages received by a LTEP are transmitted via the downlink.

Fig. 6: Mapping of LSEP/LTEP to UL and DL directions.



Source: 5G-ACIA / ZVEI

5 Traffic model parameters

The primary purpose of the traffic model is to provide a basis for assessing required network resources, i.e. what resources are needed to sustain a certain number and density of devices with a certain traffic pattern.

Due to the nature of the local application functions, it can be assumed that 5G signaling traffic (e.g. traffic for UE authentication, hand-over, connection establishment, etc.) is negligible and does not have to be modeled with specific parameters.

5.1 Traffic-related parameters

5.1.1 Message size

The message size is the number of bytes that are transferred between the local application function and the communication function at the reference interface. The message size is primarily determined by the application. However, if, for example, Ethernet frames are used by the local application function the minimum message size is 64 bytes. When IP frames are used the IP (v4 or v6) frame structure will determine the minimum message size.

Message size is given for each logical link separately. Within a logical link the message size may vary, depending on whether a message is being sent or received by the local application function via LSEP and LTEP, respectively.

5.1.2 Transfer interval

The transfer interval is the time between two consecutive transfers of user data between the local application function and the communication function via the reference interface. Transfer intervals are given for each logical link and may vary, depending on whether messages are being sent or received.

5.1.3 Data rate

The data rate is the specific number of bytes transferred between the local application function and the communication function via the logical endpoint within a specific time interval, e.g. a second.

This parameter is typically given as follows:

- average data rate, measured over an extended time period (e.g. an hour); this value indicates the average load a network will have to support, and
- peak data rate, measured over a short time period (e.g. 1 to 10 seconds);
- Average and peak data rates are given for each logical link and may vary depending on whether data is being sent or received. Similar to the message size, the data rate includes L2 and L3 header overhead.

5.2 Network-related parameters

5.2.1 Radio link direction

Data can be sent from the local application function or received by the local application function, as outlined in the logical endpoint definition. Where the local application function sends data, it is transferred via the radio uplink, when data is received, it is transferred via the downlink.

5.2.2 Communication paths

All parameters described in the sections above are applicable to P2Pand D2D communication paths.

P2P – messages are sent and received via the UL and DL using individual addresses. When an application sends information to multiple receivers, each message must be sent individually to each receiver.

D2D – messages are sent from one device to another device directly using the 3GPP sidelink mechanism without using the resources of the communications network. Setting-up the D2D connection via the communications network imposes a traffic load that is negligible since the D2D connection is expected to be of extensive duration (hours or even days).

P2M – messages are sent from a device to multiple other devices. The sending device uses a P2P path to the network, while the network used P2M over the radio DL towards the receivers.

6 Mobility model

Awareness of device mobility is important when modelling user data traffic, in particular with regard to:

- Handover probability
- Load variation across cells
- Receive power variation for both the uplink and the downlink

In an advanced, flexible factory, many assets containing 5G devices, such as mobile robots and many tools and machines, can change location. In addition, automated guided vehicles (AGV) are commonly deployed to move items between machines. It is also highly likely that workers are connected to the factory network. Some vehicles, in particular AGVs, may be restricted to predefined corridors. However, some 5G devices may not be mobile at all. These are excluded from the mobility model.

Also excluded are devices that only move within a very limited geographical area of a few meters, such as e.g rotating devices with sensors/actuators in a motion control system of a machine. Devices of this kind typically have little impact on the handover probability, load variation across cells, or receive power variation.

The traffic model needs to define the following additional parameters:
Average distance between mobile devices: This parameter is employed to model the number of devices present in a given geographical area. The distance between devices is expressed as an exponential random variable with the average equal to this parameter.

Mobile device type: Mobile device types are characterized by their size, velocity and their planned trajectory. It is also important that the traffic model includes the time when the device is not moving (pause). For example, this occurs when an AGV is loading or unloading items. In addition, some types may be restricted to certain areas of the factory. Examples are given in Table 2.

Mobile device heterogeneity: This parameter describes the statistical distribution of mobile device types within a factory or within a certain area of the factory.

Table 2: Example mobile device types

Device type	Velocity [km/h]	Restricted area	Predefined path	Pause time [s]
Drones	15-50	no	yes	0-50
Connected worker	5-10	yes	no	5-3600
Connected workpieces	1-15	yes	yes	5-3600
AGVs	1-50	yes	yes	5-3600
Mobile robots	1-15	yes	yes	5-3600

Source: 5G-ACIA / ZVEI

7 Conclusion and outlook

This white paper presents a traffic model that can be used by OT companies and by 5G service providers as a mutually agreed method to describe expected radio traffic. The model must be applied to each use case individually, taking into account the specific characteristics of the use case and corresponding application functions.

While a more generic traffic model would comprise a large number of parameters, this traffic model comprises only those parameters relevant to a wireless 5G network, i.e. relevant to assessing required network resources.

A reference interface is described where all parameters of this traffic model can be unambiguously defined and, depending on the specific device implementation, measured.

In its present version, the majority of traffic model parameters are defined using average values. In actual use case implementations, the values may vary significantly; such variations may have an impact on 5G network dimensioning and design. In a next release of this white paper, the traffic model will be enhanced with a description of such variations. Last but not least it should be noted that this traffic model is not, on its own, sufficient to assess the required frequency bandwidth of a 5G network. This assessment would require more in-depth analysis of e.g. the geographical topology, radio access network design, frequency range, etc.

8 References and abbreviations

UL	Uplink
DL	Downlink
UE	User equipment
HMI	Human-machine interface
P2P	Point to point
P2M	Point to multipoint
D2D	Device to device
LSEP	Logical source endpoint
LTEP	Logical target end point
SAP	Service access point

[1] 3GPP TS 22.104

[2] 3GPP TS 23.501

9 Annex A.1: Traffic model applied to example use cases

As a guide to companies implementing real-world industrial use cases with 5G networks, this appendix applies the traffic model described in this white paper to a number of example use cases. To this end, the use cases defined in 3GPP 22.104 have been employed. It should be noted that the examples represent just a few typical use cases and make no claim to be comprehensive.

For real-world deployments, the applicability of the use cases described must be considered from both a technical and economic viewpoint. Not all use cases will justify 5G radio access. This white paper does not consider economic goals or constraints. It is assumed that all devices for the respective use cases are operating in environments which require wireless communications. This is most clearly the case for mobile robots and AGVs.

The generic template given below contains all traffic model parameters that must be populated with values in line with the specific use case. This template is used for each application function that participates in data communication over the radio interface of a 5G network. The generic template includes four logical links. However, in real-world scenarios, the number of logical links is unlimited and must be tailored to the specific use case. A device connected to a single sensor will only require a single logical link to be depicted, while a device connected to 100 sensors will generally be modeled by means of 100 logical links. However, in this latter case, if multiple sensors display identical behavior, they can be modeled in aggregate by means of a single logical link.

Table 3: Generic traffic model template

Attributes		Logical Link 1		Logical Link 2		Logical Link 3		Logical Link 4		Comments/ explanations
		LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	
Periodic Traffic	Transfer Interval									A use case may need more that one logical links in case e.g. more Sensors/Actuators (or controllers) are connected to a single cellular IO/GW, i.e. only the IO/GW has a radio i/f but not each S/A.
	Explanation: This is the average time interval (in ms) when a user data message is sent (LSEP)from the local application function to the communication function (uplink), or received (LTEP) from the communication function (LTEP, downlink). Note 1: This is the „Transfer Interval of vertical application" Ref TS 22.104 Figure C5-2 Note 2: This is not the latency!									
	Message Size									Periodic and aperiodic&Burst Traffic attributes are mutually exclusive for a single logical link. A use case may require both periodic and aperiodic traffic, in which case thos traffic type will be modelled in different logical links.
	Explanation: This is the value in bytes of the average user data frame including the Ethernet and/or IP header. Note 3: Message sizes may differ for sending and receiving directions									
Aperiodic and Burst Traffic	Data Rate									
	average									
	peak									
	Explanation: This is the value in bytes of the average user data frame including the Ethernet and/or IP header. Note 3: Message sizes may differ for sending and receiving directions									
All Traffic	Radio Link Direction	uplink	downlink	uplink	downlink	uplink	downlink	uplink	downlink	The attributes ‚Radio Link Direction‘ and ‚Communication Path‘ apply to both periodic and aperiodic traffic types.
	Explanation: data can be sent from the mobile device to the radio network (LSEP, uplink) or is received from the radio network (LTEP, downlink)									
	Communication Path	P2P	P2P	P2P	P2P	P2P	P2P	P2P	P2P	
	Explanation: data can be transferred via the network, or from one device to another device omitting the network									

Traffic volume (kbit/s)	
Sum uplink	00,00
Sum downlink	00,00

Source: 5G-ACIA / ZVEI

9.1 Use case: motion control, mobile controller

In this use case, a controller with radio network connectivity communicates with two remote sensors (logical links 1 and 2) and with a remote actuator (logical link 3). The two sensors send a message of small size every 1 ms to the controller. The controller sends a command to the actuator every 10 ms and receives an acknowledgement in return.

Small-sized messages might potentially be just a few bytes in length. However it is assumed that they are transmitted as L2 frames over the reference interface (Figure 1) with 64 bytes as the minimum size.

With these assumed values for the traffic model parameters, the controller would be expected to generate traffic over the radio interface of 50 kbit/s for the uplink and 1550 kbit/s for the downlink.

Table 4: Motion control

Attributes		Logical Link 1		Logical Link 2		Logical Link 3		Logical Link 4		Comments/ explanations
		LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	
Periodic Traffic	Transfer Interval		1,00		1,00		1,00	10,00	10,00	
	Message Size		64		64		64	64	64	
Aperiodic and Burst Traffic	Data Rate									
	average									
	peak									
All Traffic	Radio Link Direction	uplink	downlink	uplink	downlink	uplink	downlink	uplink	downlink	
	Communication Path	P2P	P2P	P2P	P2P	P2P	P2P	P2P	P2P	

Traffic volume (kbit/s)	
Sum uplink	50,00
Sum downlink	1.550,00

Source: 5G-ACIA / ZVEI

9.2 Use case: closed loop control, mobile I/O gateway

A mobile I/O gateway with radio network connectivity connects locally (wired) to two sensors (logical link 1 and 2) and one actuator (logical link 3) and communicates with a remote controller. The two sensors send a small-sized message every 1 ms via the I/O gateway to the remote controller; these messages are not acknowledged by the remote controller. The actuator receives a medium-size (256 byte) message from the remote controller every 1 ms, and acknowledges that message with a small-sized message of its own.

With these assumed values for the traffic model parameters, the I/O device will generate traffic over the radio interface of 1500 kbit/s on the uplink and 2000 kbit/s on the downlink.

Table 5: Close Loop Control

Attributes		Logical Link 1		Logical Link 2		Logical Link 3		Logical Link 4		Comments/ explanations
		LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	
Periodic Traffic	Transfer Interval	1,00		1,00		1,00	1,00			
	Message Size	64		64		64	256			
Aperiodic and Burst Traffic	Data Rate									
	average									
	peak									
All Traffic	Radio Link Direction	uplink	downlink	uplink	downlink	uplink	downlink	uplink	downlink	
	Communication Path	P2P	P2P	P2P	P2P	P2P	P2P	P2P	P2P	

Traffic volume (kbit/s)	
Sum uplink	1.500,00
Sum downlink	2.000,00

Source: 5G-ACIA / ZVEI

9.3 Use case: Process monitoring

A mobile I/O gateway with radio network connectivity connects locally (wired) to two sensors (logical link 1 and 2) and communicates with a remote compute entity such as a controller or a SCADA system. The two sensors are polled by the remote compute entity and respond to that poll with their captured values; polling is performed every 20 ms on average.

With these assumed values for the traffic model parameters that I/O device will generate traffic over the radio interface of 50 kbit/s uplink and 50 kbit/s downlink.

Table 6: Process monitoring

Attributes		Logical Link 1		Logical Link 2		Logical Link 3		Logical Link 4		Comments/ explanations
		LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	
Periodic Traffic	Transfer Interval	20,00	20,00	20,00	20,00					
	Message Size	64	64	64	64					
Aperiodic and Burst Traffic	Data Rate									
	average									
	peak									
All Traffic	Radio Link Direction	uplink	downlink	uplink	downlink	uplink	downlink	uplink	downlink	
	Communication Path	P2P	P2P	P2P	P2P	P2P	P2P	P2P	P2P	

Traffic volume (kbit/s)	
Sum uplink	50,00
Sum downlink	50,00

Source: 5G-ACIA / ZVEI

9.4 Use case: Mobile robot

A mobile I/O gateway with radio network connectivity mounted on a mobile robot or an AGV connects locally (wired) to two high-definition cameras (logical link 1 and 2) and to 2 actuators (logical link 3 and 4).

The camera on logical link 1 sends a continuous high-definition video stream to a remote controller at a data rate of 8 Mbit/s and receives corresponding acknowledgements (10 kbit/s). The second camera (logical link 2) only sends a video stream when the mobile robot (AGV) reaches a defined position where a second image is required by the remote controller. This second camera has the same resolution and the same peak data rate as the first camera but will have a lower average data rate as it only transmits images intermittently.

The actuator communicating via logical link 3 receives a command from the remote controller every 10 ms, and sends a corresponding acknowledgement. The actuator using logical link 4 does the same every 1 ms. All actuator messages are small in size.

With these assumed values for the traffic model parameters, the I/O device will generate traffic over the radio interface of 9 Mbit/s on the uplink and 560 kbit/s on the downlink.

Table 7: Mobile robot

Attributes		Logical Link 1		Logical Link 2		Logical Link 3		Logical Link 4		Comments/ explanations
		LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	
Periodic Traffic	Transfer Interval					10,00	10,00	1,00	1,00	
	Message Size					64	64	64	64	
Aperiodic and Burst Traffic	Data Rate									
	average	8.000,00	10,00	500,00	1,00					
	peak	8.000,00	10,00	4.000,00	10,00					
All Traffic	Radio Link Direction	uplink	downlink	uplink	downlink	uplink	downlink	uplink	downlink	
	Communication Path	P2P	P2P	P2P	P2P	P2P	P2P	P2P	P2P	

Traffic volume (kbit/s)	
Sum uplink	9.050,00
Sum downlink	561,00

Source: 5G-ACIA / ZVEI

9.5 Use case: human-machine interface (HMI)

A mobile HMI device with radio network connectivity possesses an emergency button system (logical link 1) that communicates with a remote controller and sends a watchdog supervision message every 5 ms which is acknowledged by the remote controller. The HMI also occasionally receives a high-definition video data stream (logical link 2) at a peak data rate of 8 Mbit/s.

With these assumed values for the traffic model parameters, the HMI device will generate traffic over the radio interface of 200 kbit/s on the uplink and 4 Mbit/s on the downlink.

Table 8: HMI

Attributes		Logical Link 1		Logical Link 2		Logical Link 3		Logical Link 4		Comments/ explanations
		LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	
Periodic Traffic	Transfer Interval	5,00	5,00							
	Message Size	128	64							
Aperiodic and Burst Traffic	Data Rate									
	average			10,00	4.000,00					
	peak			10,00	8.000,00					
All Traffic	Radio Link Direction	uplink	downlink	uplink	downlink	uplink	downlink	uplink	downlink	
	Communication Path	P2P	P2P	P2P	P2P	P2P	P2P	P2P	P2P	

Traffic volume (kbit/s)	
Sum uplink	210,00
Sum downlink	4.100,00

Source: 5G-ACIA / ZVEI

9.6 Use case: Closed-loop control for process automation

A mobile I/O gateway with radio network connectivity connects locally (wired) to two groups of sensors (logical link 1 and 2) and one group of actuators (logical link 3), and communicates with a remote controller. The I/O gateway captures a value from each sensor in the first group and sends a message with the combined values of medium size (256 bytes) every 200 ms, and sends a smaller-sized message with the values from the other group (128 bytes) every 500 ms via the I/O gateway to the remote controller. These messages are not acknowledged by the remote controller. The I/O gateway receives a message with the values from the group of actuators (128 bytes) every 200 ms from the remote controller and sends back an acknowledgement message of the same size (128 bytes).

With these assumed values for the traffic model parameters, the the I/O device will generate traffic over the radio interface of 17 kbit/s on the uplink and 5 kbit/s on the downlink.

Table 9: Closed-loop control for process automation

Attributes		Logical Link 1 LSEP	Logical Link 1 LTEP	Logical Link 2 LSEP	Logical Link 2 LTEP	Logical Link 3 LSEP	Logical Link 3 LTEP	Logical Link 4 LSEP	Logical Link 4 LTEP	Comments/ explanations
Periodic Traffic	Transfer Interval	200,00		500,00		200,00	200,00			
	Message Size	256		128		128	128			
Aperiodic and Burst Traffic	Data Rate									
	average									
	peak									
All Traffic	Radio Link Direction	uplink	downlink	uplink	downlink	uplink	downlink	uplink	downlink	
	Communication Path	P2P	P2P	P2P	P2P	P2P	P2P	P2P	P2P	

Traffic volume (kbit/s)	
Sum uplink	17,00
Sum downlink	5,00

Source: 5G-ACIA / ZVEI

9.7 Use case: Control-to-control

Two or more (typically four to five) machines collaborate in a flexible, modular production environment. Each machine communicates with every other machine, with similar traffic across all links. In traditional, non-flexible scenarios, 100 Mbit/s and 1 Gbit/s wired links are used (e.g. 1 Gbit/s links for video streaming, 100 Mbit/s links for motion control). In order to enable flexible and modular scenarios, the wired connections between the machines are replaced by wireless ones. For this purpose, each machine is equipped with an I/O device (UE) connected to the controller.

The traffic is divided into periodic (on logical link 1) and aperiodic traffic (on logical link 2). The logical link 1 can be considered the aggregate of all links between the collaborating machines, in both uplink and downlink directions. The traffic is distributed across all links between the collaborating machines. Aperiodic traffic is also distributed across all links, and can be considered the aggregate of all links between the collaborating machines and any additional devices they are communicating with (e.g. various sensors).

Use case 1 – 100 Mbit/s link

For the 100 Mbit/s link, 50% periodic and 25% aperiodic traffic is assumed. Each machine sends to and receives 6.25 kB of periodic data per 1 ms interval (50 Mbit/s) via logical link 1 from the collaborating machines. Aperiodic data can vary between 0 and 3.125 kB per 1 ms interval (25 Mbit/s) via logical link 2. With these assumed values for the traffic model parameters, the traffic volume over the radio interface is on average 62 Mbit/s on the uplink and 62 Mbit/s on the downlink.

Use case 2 – 1 Gbit/s link

For the 1 Gbit/s link, 25% periodic and 50% aperiodic traffic is assumed. Each machine sends and receives 31.25 kB of periodic data per 1 ms interval (250 Mbit/s) via logical link 1. Aperiodic data can vary between 0 and 62.5 kB per 1 ms interval (500 Mbit/s) via logical link 1. With these assumed values for the traffic model parameters, the traffic volume over the radio interface is on average 500 Mbit/s on the uplink and 500 Mbit/s on the downlink.

Table 10: Control-to-control – 100 Mbit/s link

Attributes		Logical Link 1		Logical Link 2		Logical Link 3		Logical Link 4		Comments/ explanations
		LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	
Periodic Traffic	Transfer Interval	1,00	1,00							
	Message Size	6.250	6.250							
Aperiodic and Burst Traffic	Data Rate									
	average			12.500,00	12.500,00					
	peak			25.000,00	25.000,00					
All Traffic	Radio Link Direction	uplink	downlink	uplink	downlink	uplink	downlink	uplink	downlink	
	Communication Path	P2P	P2P	P2P	P2P	P2P	P2P	P2P	P2P	

Traffic volume (kbit/s)	
Sum uplink	61.328,13
Sum downlink	61.328,13

Source: 5G-ACIA / ZVEI

Table 11: Control-to-control – 1 Gbit/s link

Attributes		Logical Link 1		Logical Link 2		Logical Link 3		Logical Link 4		Comments/ explanations
		LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	LSEP	LTEP	
Periodic Traffic	Transfer Interval	1,00	1,00							
	Message Size	31.250	31.250							
Aperiodic and Burst Traffic	Data Rate									
	average			250.000,00	250.000,00					
	peak			500.000,00	500.000,00					
All Traffic	Radio Link Direction	uplink	downlink	uplink	downlink	uplink	downlink	uplink	downlink	
	Communication Path	P2P	P2P	P2P	P2P	P2P	P2P	P2P	P2P	

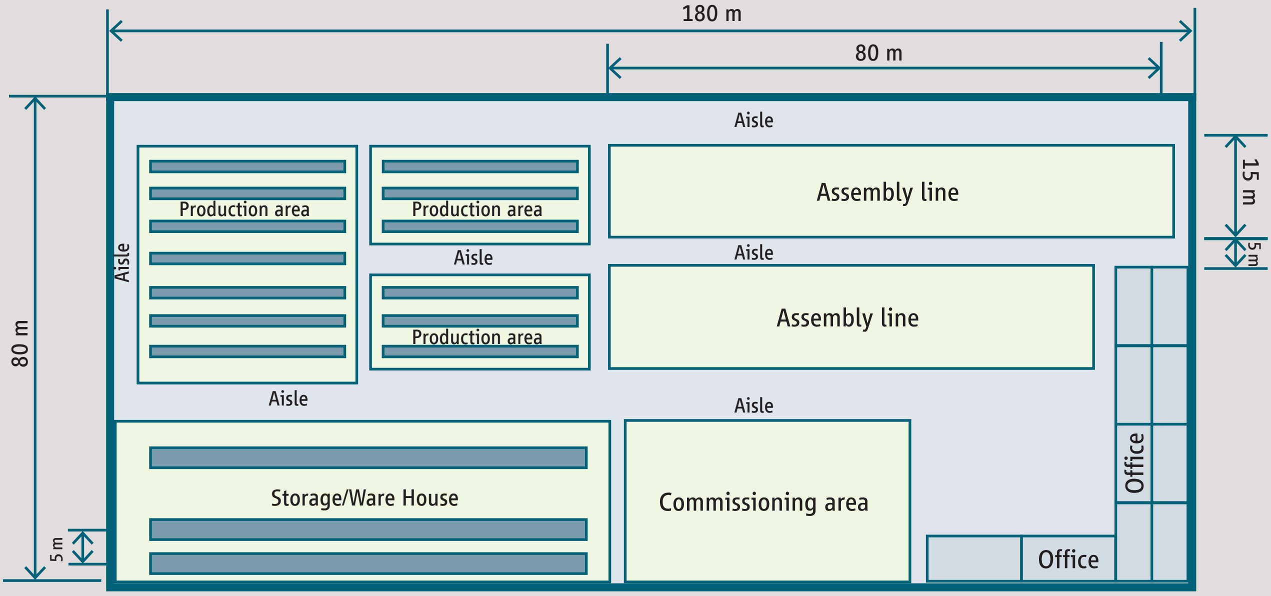
Traffic volume (kbit/s)	
Sum uplink	494.140,63
Sum downlink	494.140,63

Source: 5G-ACIA / ZVEI

10 Annex A.2: Distributed devices in an example factory

This Annex A.2 presents an example implementation of the use cases described in Annex A.1 applied to the factory layout given in Figure 7. The layout represents a typical factory for discrete production and assembly. It comprises a production area, assembly areas, a warehouse, a commissioning space and office cubicles, spanning a total of approximately 15,000 square meters with a ceiling 30 m high.

Fig. 7: Indoor industrial facility



Source: 5G-ACIA / ZVEI

3GPP TS 22.104 specifies the expected device density for the use cases given in Annex A.1. The table below shows the expected number of devices and the expected data rates. Three deployment scenarios are considered: small-scale, large-scale deployment and inbound logistics. Small-scale in this context reflects an initial roll-out of half the number of devices (half the density) defined in TS 22.104, typical to a brown-field factory. Large-scale corresponds to the wide deployment of 5G-based devices in a new or highly flexible factory with modular production cells. The inbound logistics scenario reflects the deployment of many more mobile robots and AGVs but on the other hand fewer motion-control use cases.

The example calculations in table 12 for these scenarios give values for the radio uplink and downlink traffic.

Table 12: Device deployment scenarios and corresponding 5G traffic (note 1: no values specified in TS 22.104)

Use case	Device density [#/sqm]	# of devices	UL traffic [Mbit/s]	DL traffic [Mbit/s]
Small scale deployment scenario				
Process Monitoring	n/a	20		
Close-Loop-Control	0.002	15		
Motion Control	0.2	150		
Mobile Robot	0.001	8		
HMI	(note 1)	7		
Control-Control 100	0.003	0		
			105	**300**
Large scale deployment scenario				
Process Monitoring	n/a	40		
Close-Loop-Control	0.002	30		
Motion Control	0.2	300		
Mobile Robot	0.001	40		
HMI	n/a (note 1)	14		
Control-Control 100	0.003	2		
			550	**730**
Inbound logistics deployment scenario				
Process Monitoring	n/a	20		
Close-Loop-Control	0.002	30		
Motion Control	0.2	30		
Mobile Robot	0.001	40		
HMI	(note 1)	14		
Control-Control 100	0.003	0		
			410	**190**

Source: 5G-ACIA / ZVEI

It should be noted that the above traffic volumes depend to a very large extent on the use case mix. The traffic volumes given include periodic, aperiodic and aperiodic and burst traffic types that are subject to differing quality of service classes within a 5G network. The composition of traffic types varies according to the use case, as indicated in tables 4 – 11 in Annex A.1.

In the inbound logistics scenario, for example, uplink traffic is higher than downlink traffic while that relationship is reversed for the small-scale and large-scale scenarios.

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5G Alliance for Connected Industries and
Automation (5G-ACIA),
a Working Party of ZVEI
Lyoner Strasse 9
60528 Frankfurt am Main, Germany
Phone: +49 69 6302-424
Fax: +49 69 6302-319
Email: info@5g-acia.org
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