Survey of Scenarios for Measurement of Reliable Wireless Communication in 5G

Matthias Herlich, Thomas Pfeiffenberger, Jia Lei Du, Peter Dorfinger

Salzburg Research, `firstname.lastname@salzburgresearch.at`

Abstract. In the future many parts of our lives will increasingly depend on wireless communication. Therefore, wireless communication should be reliable. Different scenarios need different methods to measure the reliability (e.g., active and passive). In this paper, we survey scenarios in which reliable communication is important and select two scenarios which are suited to measure the reliability of the wireless networks.
Based on literature search and interviews with experts in the field we determined two scenarios which demand a wide range of measurement methods: (1) vehicles transmitting collision warnings at intersections and (2) wireless emergency-stop buttons in factories. Both scenarios need wireless communication, but are so different they need different methods to measure the reliability of the wireless system.
Because the selected scenarios have different properties, the methods that can measure the reliability in these scenarios, will also be able to measure the reliability in many other scenarios. To be able to compare methods to measure reliability of wireless networks, researchers should focus on the same scenarios. We propose to use the scenarios described in this paper.

1 Introduction

Wireless communication has become an important technology for many people in their daily lives. Mobile phones and smart phones are used all over the globe. The main advantage of wireless communication is that it reduces the overhead of connecting wires to devices and that it allows devices to communicate that cannot be connected with wires.

The biggest disadvantage of wireless communication is that its operation depends on the environment. When a connection is wired, outside influences have little effect on the communication. In contrast, the environment in which wireless communication is used has a large effect on its performance. There are different metrics for performance, but one of the most important ones is reliability. The reliability of a system describes its probability to successfully handle requests (for the exact definition we use, see section 2).

People have learned to cope with unreliable wireless networks: They do not expect to be able to make phone calls in parking garages and postpone calls when the connection is unreliable. That is, people are flexible and adapt to the reliability of the wireless network. Machines also use wireless communication, but until now this has mostly been limited to communication that is not critical. Therefore, temporary losses of the ability to communicate have not been a major problem.

In the future machines will increasingly use wireless communication for mission-critical communication. For this to be possible, wireless communication must be reliable at each location where machines need it. To describe the reliability, many channel models and characterizations (e.g., [18]) have been developed for wireless communication. However, in other areas where failures of technology can cause death (e.g., medical devices, drugs, mechanical engineering) rigorous protocols are in place to ensure that each product has the desired properties. However, methods to monitor the end-to-end reliability of wireless networks are not yet available.

Because we expect an increased research interest on methods to measure reliability in the future, such research should be comparable (see our definition of reliability in the next section). To achieve this, researchers should focus on the same scenarios. In these scenarios reliable wireless communication should be essential. To cover a wide range of scenarios, the two selected scenarios should need different methods to measure the reliability of the wireless communication.

The contribution of this paper is a survey of scenarios in which reliable wireless communication is essential and a selection of two scenarios which need different methods to determine the reliability. To do this, we describe types of measurements in Section 2 and give a broad overview of the areas for wireless communication in section 3. In Sections 4 and 5 we describe scenarios of automotive and industry in more detail before we compare the selected scenarios in Section 6. To ensure a wide range of possible applications and comparability for methods to measure reliability, researchers should focus on these scenarios.

2 Measurement Methods

For a scenario to be included in this survey, it has to depend on reliable wireless communication. For this purpose we define **reliability** as the "packet delivery rate between two end points with a given maximum transmission duration", where the rate is the fraction of delivered error-free packets divided by the number of packets sent. For the receiver to use the packet it is necessary to receive the packet with the correct content. We consider the reliability to be measured at the application level on a per packet basis. That is, the reliability is measured after retransmissions and correction mechanisms (such as Hybrid automatic repeat request, HARQ). However, also the time limit is measured after the application of these mechanisms. While there are many similar definitions of reliability [7,29,23], we consider this the most useful one for our project.

We want the scenarios to be relevant for the sector they appear in. That is, they should have a high technical impact. The value of its application does not have to be available in the near future, but it should have the potential for large changes and have a reasonable chance to be implemented.

2.1 Active and Passive Measurements

Scenarios need different measurements: During **passive** measurements, the measurement system does not generate wireless transmissions, but only monitors wireless traffic that is already transmitted. For this to be possible wireless communication must be used in the scenario already. Ideally the traffic is of high volume to quickly generate measurement data. The advantage of passive measurements is that the effect on the environment is low (only the measurement hardware has to be added, but no additional transmissions are generated).

During **active** measurements, the measurement system generates traffic itself. Thus, it does not depend on a communication system already being in place. However, with active measurements the effect on other wireless transmissions in the area have to be taken into account.

2.2 Periodic and Event-based Traffic

The traffic that is generated by machine-to-machine communication can be categorized by the regularity of the traffic. **Periodic** traffic consists of packets of the same size that are transmitted in constant intervals. That is, the pattern of the traffic is deterministic. Only the content of the packets cannot be predicted. This type of traffic is usually generated when machines are monitored and the data is archived for later analysis or machines need to coordinate in predefined groups.

In **event-based** traffic the interval between two consecutive transmissions does not follow a regular pattern, but is based on some external event. This type of traffic usually occurs when notifications are generated based on external events.

3 Overview

Many overview papers have been written about the potential of wireless communication for diverse sectors. In contrast to the broad descriptions in most of these, our goal is to determine scenarios which represent the needs for different methods to determine the reliability.

The 5G-PPP document about vertical industries for 5G [5] describes the main verticals for 5G as: Factory of the future, Energy, e-Health, Automotive, and Media & Entertainment. The document provides an overview of the verticals and gives examples for quantified requirements. However, it does not give an in depth analysis of the individual vertical sectors. The 5G-PPP provides more details in the individual documents for each vertical (e.g., for factories [3] and automotive [4]). We will describe the relation to measurements of reliability of these documents in Sections 4 and 5.

The German position paper "Resiliente Netze mit Funkzugang" ("resilient networks with wireless access") [16] is part of the German initiative industrial radio[1]. It focuses on application perspectives and technological aspects of resilient wireless networks. Also, companies (e.g., Siemens [26]) have described their requirements on 5G or wireless communication in general. Such industrial white papers describe what the companies consider important. Yet, they might contain a biased view from the perspective of the company.

The health sector is also considered a vertical sector for 5G by the 5G-PPP [2] and the wireless world research forum [27]. They expect that wireless communication will enable physicians to collect more data and thereby create more effective treatments. This overlaps with the general trend of Internet of Things (IoT) that places sensors and actuators in physical devices.

The railway sector is usually not listed as one of the high priority verticals for 5G. One of the reasons for this is that the railway sector already has a set of standards [22] based on GSM-R in place that allow monitoring and support operation of trains with the The European Rail Traffic Management System ERTMS[2]. Updating ERTMS to a modern communication technology will provide train operators with more data rate and a more reliable communication network. In addition to the passengers on the train benefit from 5G with increased media and entertainment comfort.

To determine which sectors to focus on, we determined which sectors are most in line with strengths in Europe and especially Austria. The European Union [12] and especially Austria [10] see one of their strengths in factories of the future. Another sector of great importance is the automotive sector [11,9].

In the following sections we describe selected scenarios from the automotive and industrial sectors, which focus on reliability. The information is collected from published work as well as interviews with experts in the field (which we were asked to keep confidential).

4 Automotive

The automotive sector is expected to change dramatically in the next decades. Assistance systems are getting more prevalent and autonomous cars are getting closer to production. An important background change is that cars are communicating with each other and with infrastructure. The change is spearheaded by the 5G Automotive Association (5GAA[3]) [6]. For Austria [11,9] and Germany [19] the communication of vehicles is an important area of research.

4.1 Communication

The communication of vehicles can be grouped in three categories: in-vehicle, vehicle-to-vehicle and vehicle-to-infrastructure.

In-vehicle communication allows different parts of the same car to communicate with each other. This has been a standard for many decades and is usually

[1] `http://industrialradio.de`
[2] `http://www.ertms.net`
[3] `http://5gaa.org`

done by wired connections. Only recently have there been efforts to use wireless communication where wired communication is infeasible or expensive.

Vehicle-to-vehicle communication allows a car to send messages to other cars. Such a message can, for example, be a collision warning. For most scenarios cars only need to communicate with other cars that are close-by. In contrast to in-vehicle communication, vehicle-to-vehicle cannot be done by wires, because the cars move independently of each other and cannot be interconnected for any individual communication.

Vehicle-to-infrastructure communication is between a car and a stationary unit. This can, for example, be a red light at an intersection. Just as vehicle-to-vehicle communication, it is not feasible to provide vehicle-to-infrastructure communication by wires. There are more types of vehicular communication, which are summarized as vehicle-to-everything.

The European Telecommunications Standards Institute (ETSI) describes the requirements vehicles have when using an LTE network [14]. While these are described for LTE, the general concepts also hold for 5G networks.

4.2 Technologies

The most important wireless communication technologies for the automotive sector are based on next generation cellular mobile networks (5G) and on WiFi.

The 5G-PPP expects **5G** to be an important wireless communication technology in the automotive sector [4]. As 5G aims to be a single interface for all kinds of wireless communication it seems to be the ideal technology to provide vehicles with local communication and connectivity to the Internet using a single technology. However, it is unclear as of now, whether there will be a single interface 5G will provide to the automotive sector or if local and global communication will have different interfaces.

IEEE 802.11p is an adaption of **WiFi** for automotive environments [24]. The most important changes have been made on the physical layer to cope with the speeds at which vehicles move compared to the typical office and home use of other WiFi standards. Built on top of 802.11p are several technologies that provide higher level features for an automotive environment. The most important one (at least for Europe) is ITS-G5 as defined by the ETSI [13]. ITS-G5 is used, for example, in the highway corridor from Rotterdam to Vienna[4].

4.3 Reliability

In the past wireless communication has only been used for non-critical communication such as updating maps of navigation systems. The trend is to transmit information that is time-critical. From traffic-jam warnings, which have acceptable latency in the order of minutes towards collision warnings and control loops for highway platooning, which have acceptable latency of tens or hundreds of milliseconds.

[4] `http://www.eco-at.info`

When the acceptable latency is high, a transmission can be made reliable using retransmissions. However, a low acceptable latency limits the number of possible retransmissions and, thus, also the reliability. Hence, high reliability is hard mostly for low latency applications. Other methods to ensure reliability are costly, because they need bandwidth and infrastructure. Hence, providing high reliability is only a focus, when (human) lives are at risk or communication failures are expensive (e.g., damage to vehicles).

4.4 Scenarios

The next step is to determine which automotive scenario is suited best to measure the reliability of wireless communication. We consider only scenarios, which have quantified requirements on reliability and latency.

Automated overtaking [4] on highways is considered relatively easy, because the road is mostly straight, vehicles move in only one direction and there are multiple lanes. However, autonomous vehicles will also have to overtake other vehicles on curvy rural roads, with two-way traffic and one lane per direction. Especially on rural roads an automated vehicle can benefit from communication with other vehicles to safely and comfortably overtake.

Cooperative collision avoidance [4] allows vehicles to communicate to prevent accidents. Autonomous vehicles should be able to handle most situations they encounter using only their built in sensors. However, sometimes situations may arise where the built in sensors are not enough to prevent a collision. In these cases wireless communication can avoid collisions. Human-piloted vehicles can also benefit from collision warnings, if the warnings are implemented such that the driver can react quickly. An example, where cooperative collision avoidance can be used are urban intersections. Collision avoidance can be implemented with trajectory announcements or handshake and status updates.

In **high-density platoons** [4] vehicles follow each other at close distances. This increases efficiency of traffic and reduces fuel consumption [8]. When vehicles use sensors to detect changes in the speed of the vehicle in front, they have to wait for the vehicle in front to change its speed measurably to react. With wireless communication the vehicle in front can inform the vehicle(s) behind it the moment it detects a dangerous situation. Thus, using wireless communication in platoons, reduces the distances and thereby increases efficiency.

Table 1 summarizes the requirements of the scenarios we described in this section. The values presented should not be understood as definitive values, but only provide an estimate for the requirements on this level of aggregation.

4.5 Selection

We select the scenario of cooperative collision avoidance, because: (1) It is possible to measure the reliability of wireless communication at an urban intersection without the need to move at high speeds (such as on highways or rural roads). (2) The wireless environment seems challenging (Non-line-of-sight, many moving objects, many other wireless signals).

Table 1. Requirements of automotive scenarios (data source [4])

Scenario	Latency [ms]	Reliability [%]
Automated Overtake	10	99.999
Collision Avoidance: Handshake	100	99.999
Collision Avoidance: Status Updates	10	99.9
High Density Platooning	10	99.999

5 Industry

The industrial sector is expected to continue to automate more processes and factories will be more dynamic. That is, they have to change more often instead of producing the same good for a long time. Drivers for this are increased customization of products and the need to reduce the time from design to market of a product. This is part of the general trend towards Industry 4.0 [20,21]. The 5G Alliance for Connected Industries and Automation (5G-ACIA[5]) plans to push the requirements of industry into 5G.

5.1 Communication

The use of wireless communication can be grouped in three categories: within factories, in the supply chain, and during the product life-cycle [3].

To make factories more dynamic, machines **within the factory** need to communicate more. Machines will increasingly communicate by wireless communication, because this reduces the overhead of connecting communication networks when machines are moved. Additionally, wireless communication will allow devices to transmit from locations, where it is impossible to connect them with wires (e.g., inside sealed containers). For communication inside the factory low latency and high reliability are important [28]. However, especially requirements on latency and reliability cannot be fulfilled with todays technologies [17].

Wireless communication can quickly identify parts and connect physical parts with their virtual representation and history. This will improve the way products flow through the **supply chain**. Following each item individually through the supply chain is necessary to customize each product.

Wireless communication will not cease after a product is sold: Monitoring the product will be possible during the complete **product life cycle**. Wireless communication will allow devices to send their usage patterns to the manufacturer to improve the next generation of products. Additionally, it can be used to ensure that each product is correctly disposed of after the end-of-life.

5.2 Technologies

Because wireless communication can be used for different tasks in the industrial sector, different technologies have been developed.

[5] `https://www.5g-acia.org`

Because **WiFi** is extensively used outside of the industrial sector, it is reused to reduce costs. The biggest drawback of WiFi in the industrial setting is that WiFi was not created for the requirements that industry has. Nevertheless, for much of the non-critical communication it can be used. Standard WiFi has been adapted for industrial applications in proprietary standards.

Wired communication technologies are established in the industrial sector. Some of these have been **adapted for wireless** use. For example, the Highway Addressable Remote Transducer (HART) Protocol can be used wirelessly using WirelessHART. Protocols, which have been adapted from wired protocols, are generally implemented with a specific focus and capability. However, the design and implementation of modern wireless communication systems has become so complex, that implementing a custom system for each use case is expensive.

The target market of **5G** is very broad. This however makes it possible to spread the development cost of the technology over many devices. Thus, technologies that are too expensive to develop for a single-use wireless system can be used by all 5G devices as the development cost is shared. The communication in the supply chain and over the life-cycle of a product can reuse the infrastructure that will be built and can be shared with all other 5G applications. Communication within a factory usually has much higher requirements on the quality of service (see next section) than communication outside the factory. Thus, using a publicly available 5G network will not be enough for in-factory communication. 5G might provide private cells for dedicated operation within factories.

5.3 Reliability

To monitor the life-cycle of a product the most pressing problem is to keep the cost of the communication low. Usually infrequent status updates are enough to gain insights into the usage of the products. When parts of a product are traced in the supply chain, the requirements on the reliability of the wireless communication are higher, because the tracking should be continuous, but it does not require millisecond responsiveness.

The requirements on the wireless system are highest for the in-factory scenarios: Here the reliability and tolerable latency are strictly limited. Because the demands of non-critical monitoring tasks are moderate, these have been approached before 5G already. However, production-critical tasks have rarely been executed over wireless communication. The German industrial Radio Initiative has collected profiles of wireless requirements in industry [30].

5.4 Scenarios

In this section we will summarize industrial scenarios in which reliability is important. From these scenarios we select one that is most suited to demonstrate the use of methods to determine the reliability. Details about the scenarios are available in the corresponding references.

Table 2 shows a summary of the requirements on wireless communication performance from different documents. The requirements on latency are in the

Table 2. Requirements of industrial scenarios

Scenario	Latency [ms]	Reliability [%]
Diagnosis & Maintenance [15]	20	99.99
Discrete Production [15]	1	99.9999999
Discrete Automation [1]	10	99.99
Manufacturing [16]	1	99.9999
Process Automation [16]	20	99.9999
Process Automation [15]	50	99.999
Process Automation (monitoring) [1]	50	99.9
Process Automation (remote control) [1]	50	99.9999

range of 1 ms to 50 ms and the reliability in the range of 99.9 % to 99.999 999 9 %. However, most requirements can be fulfilled with 10 ms latency and a reliability of 99.9999 %.

5.5 Selection

A concrete scenario where reliability is important is a wireless emergency-stop button. An emergency-stop button is a button that an operator of a machine can press to disable a machine. Because this safety feature can be necessary to safe human lives, it has to be highly reliable. Therefore, emergency-stop buttons have until recently always been connected by wired connections to the machines they disable.

In the past each machine had an operator and, thus, each machine had a control panel at which the operator worked. As factories have become more automated, the number of workers was reduced and the control panels have become more complex. Now one operator manages several machines. Hence, it has become cheaper to give each operator a control panel than to attach one to every machine. To be able to work efficiently the machine operator needs to wirelessly connect to the machines.

For an emergency-stop button, which has to reliably shut down a machine, it is a problem when the wirelessly transmitted packets can be lost. Technically, the requirement is that the machines stops at maximum a predetermined time after the button was pressed. Current wireless panels with an emergency-stop button (for example, from Siemens [25] and Sigmatek [6]) implement this by repeatedly sending data packets over the wireless network, which specify that the button has not been pressed ("heartbeat"). In case of a network outage the machine will stop once it has not received a message after a given interval. While this ensures that the machine will reliably stop, a long-enough network outage will erroneously cause the machine to stop. Because this usually results in lost production, having a reliable network is important for the use of wireless emergency-stop buttons.

The wireless emergency-stop buttons transmit many data packets as the send intervals are low (in the order of 10 ms). They are a good scenario to measure the

[6] `http://www.sigmatek-automation.com/en/products/hmi/mobile-panels/`

Table 3. Comparison of scenarios

	Automotive: collision avoidance	Industrial: emergency-stop button
Access-control	none	strict
Weather susceptibility	high (outdoor)	low (indoor)
Measurement method	active	passive
Traffic profile	random	deterministic
Important for 5G	yes	yes
WiFi-based operation	yes	yes

reliability as they generate packets in regular intervals, which can be passively monitored. That is, no additional traffic needs to be generated in the usually already saturated wireless factory environment.

6 Comparison

In the previous sections we have developed two scenarios (one automotive and one industrial) which are suitable as showcases to demonstrate how to measure the reliability of wireless communication. In this section, we compare both scenarios and determine whether they overlap or need different methods of measurement. Table 3 shows a summary of the properties of the two scenarios.

The automotive scenario of collision avoidance at an urban intersection has no access control as it is located on public land. In contrast to this the wireless emergency-stop button is located within a factory and, thus, is behind access control. These two environments pose different problems for the methods to measure the reliability. Behind access control it is easier to reconstruct events than in an open environment. However, it is also more complex to get access to the measurement system, which then needs to operate with less physical access.

The two scenarios also differ in their susceptibility to weather: The industrial scenario is within a factory and, thus, the effect of weather is limited (both on the measurements and the measurement system). The automotive scenario is situated outside. Therefore, the measurement system has to be able to withstand at least a minimal amount of weather. Additionally, the wireless environment might change with the weather.

Because currently few vehicles use vehicle-to-vehicle communication, it will be necessary to actively generate measurement traffic at the intersection to generate enough data. In contrast, the emergency-stop button will generate large amounts of measurement data simply when passively monitoring the system as it transmits in short intervals. Hence, to measure the reliability of the wireless communication in all scenarios both active and passive methods are needed.

We also expect the profiles of the wireless network traffic to be different. The emergency-stop button generates packets in regular intervals. The collision warnings sent by cars will not be regularly spaced in time. It is unclear which random distribution they follow, but they will likely be different from the pattern of the emergency-stop button.

The scenarios have in common that they are examples for the use of wireless communication in sectors that are important for 5G. Additionally, both have already existing technological variants that are based on WiFi. This allows researchers to run preliminary tests while 5G hardware is not yet available.

In summary, measurement methods which are able to measure the reliability in both of these scenarios are able to measure the reliability in any scenario. Hence, these scenarios are suitable as representative scenarios for all others.

7 Conclusion

The goal of this paper was to survey scenarios in which methods to measure the reliability of wireless networks are essential. We described classes of measurement methods (active vs passive and periodic vs event-based traffic). Based on related work we determined that the most promising scenarios are in the automotive and the industrial sector.

A deeper search in the literature and interviews in these sectors lead us to two scenarios. For the automotive sector the scenario is an intersection in an urban area, where vehicles exchange collision warnings. For the industrial sector the scenario is an emergency-stop button, which regularly transmits its status to cope with outages of the wireless system.

Both scenarios are in important sectors for the future use of 5G systems and need different types of measurement techniques. Because methods, which can measure the reliability in these scenarios, need to use a variety of measurement methods, they should be able to measure the reliability in many scenarios. To make research comparable, we propose that researchers test their methods to determine the reliability of wireless networks on these two scenarios.

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