Next Generation Industrial Radio LAN for Tactile and Safety Applications

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Abstract—**Advanced industrial applications as augmented reality support for maintenance works or mobile control panels require new reliable wireless connectivity solutions that are not available today. Based on an analysis of some representative use cases, this paper identifies and quantitatively describes the resulting requirements on the wireless systems and provides a comparison to state of the art solutions. In a second part, this paper introduces a new industrial radio concept that is able to meet the derived requirements. The overall concept and the most important features allowing to meet the requirements is discussed in detail.**

Index Terms—**Industrial radio, industrial internet, WLAN, reliable wireless, tactile communication, mmWave communication, edge computing, localization, new waveform, multi-link communication, HMI, AR, safety, mobile panel**

I. INTRODUCTION

WIRELESS communication technologies bring substantial advantages into an area they are used in. As compared to wired networks, wireless communication is more flexible and scalable approach. Besides, the deployment effort usually stays low as compared to lying cables. Recent studies show, that the market for industrial wireless solutions is growing the fastest as compared to field bus and industrial Ethernet solutions [1]. Since few years, wireless solutions are evolving from monitoring and open-loop control applications to closed-loop control applications. Meanwhile, they are used not only to interconnect machines, but also to establish wireless communication links between (sub-)modules. Especially, wireless solutions are increasingly applied as an alternative to slip rings or trailing cable systems for connecting moving parts of machines to each other.

Nowadays, a number of wireless solutions are established in industrial area [2]. The preferred solutions are those operating in license-free frequency bands of 2.4 GHz and 5 GHz. The prevalent solutions are coming from consumer environment such as WLAN or Bluetooth due to their low cost. Some companies provide their proprietary solutions for further improvements to those technologies, as for instance IWLAN by Siemens. The industrial technologies such as WirelessHART, ISA 100.11a and others have been developed based on the IEEE 802.15.4 standard. In addition, completely proprietary solutions for 2.4 GHz band such as Trusted Wireless by Phoenix Contact are known. On the other hand, licence-free bands have to be shared between different systems and underlie performance-limiting regulatory restrictions. Due to these reasons, systems which have their own licensed band are increasingly getting attention. One example is Digital Enhanced Cordless Telephone (DECT) standard, which shows deterministic characteristics appropriate for industrial automation [3].

Nevertheless, industrial wireless solutions currently cover only around 4% of the industrial networks market [1]. There exist a large number of industrial applications where wireless solutions could not be employed yet. This is because of the high requirements on performance set by industrial environment. For instance, for closed-loop applications, low latency and high reliability are desired which barely can be met by the existing wireless systems.

Another application field, which was barely considered in the context of wireless communications, is human machine interaction (HMI) for industrial applications. Here, the support of users' mobility is necessary in order to provide the services as natural and seamless as possible. But still, the existing applications have to be run tethered, because common wireless solutions cannot support e.g. safety protocols due to reliability issues, thus lowering user experience. Furthermore, an emerging technology known as augmented reality cannot yet be fully realised due to weak hardware available on the market. Thus, wireless systems need to support sufficient data rates for real time video data exchange [4].

In this paper, we further concentrate on industrial HMI applications showing the bottle neck of the existing wireless technologies as well as pointing the improvements for the existing wireless technologies.

II. STATE-OF-THE-ART SOLUTIONS

This section provides an overview on the performance of wireless technologies which are well established in industrial environments. We picked for investigation performance parameters such as operating frequency band, gross data rate and latency. Moreover, mobility support of the systems was considered based on communication range as well as handover

(HO) support. Those performance parameters are also summarised in Table 1.

A. 802.15.1 – Bluetooth

Bluetooth technology was invented as a wireless replacement for RS-232 data cables for connecting consumer electronics such as keyboard or mouse to a PC. So, it aims for short range low cost solution for wireless personal area networks (WPAN) and is standardised by IEEE 802.15.1.

Bluetooth network is organized in form of piconet topology, where one master polls cyclically all connected slaves. On the one hand, deterministic latency of 8.75 ms can be achieved [5], which makes Bluetooth suitable for real-time applications. On the other hand, the number of connected slave devices is limited to 7 per piconet, which may be not sufficient for industrial environment.

Bluetooth operates in 2.4 GHz frequency band dividing it into 79 frequency channels of 1 MHz bandwidth each. This allows moderate gross data rate of 1 Mbps. Medium access as well as duplexing is organised using time division approach, which is synchronised by the master. The disadvantage of the implemented scheme is that fixed time slots are assigned to stations, regardless whether there are data to transmit, thus wasting idle slots [6].

Communication range depends on the device transmit power. There are Classes 1 to 3 defined providing transmit power of 100 mW, 2.5 mW or 1 mW as well as communication range of 100 m, 10 m or around 1 m respectively [2]. Hereby, typically used devices are of class 2. In this context, communication range may be a limiting factor for industrial usage, because there is no HO functionality supported by the standard.

B. 802.15.4

IEEE 802.15.4 defines Physical (PHY) as well as Medium Access Layer (MAC) for low-rate WPAN. The main emphasis of this standard is on provisioning low cost and low power communications. Thus, it makes it well suited for wireless sensor networks (WSN). Based on this standard, there exists a number of higher layer technologies such as ZigBee, ISA 100.11a, WirelessHART, 6LoWPAN etc. [7]

As the others are designed for applications such as house automation, Internet of Things or general purpose WSNs, WirelessHART as well as ISA 100.11a are two competing technologies developed specifically for industrial applications [7]. Both technologies use the 2.4 GHz-PHY of 802.15.4 with gross data rate of 250 kbps.

TABLE I
PERFORMANCE COMPARISON OF STATE OF THE ART WIRELESS TECHNOLOGIES

Technology	Data Rate, Mbps	Frequency band, GHz	Latency ms	Indoor range, m	Handover
WirelessHART	0.25	2.4	10	30	hard[***]
ISA 100.11a	0.25	2.4	100	30	hard[***]
Bluetooth	1	2.4	8.75	1-100	no
802.11n	144[*]	2.4/5	over 10[**]	(70)	hard
802.11ac	866.6[*]	5		(35)	hard
IWLAN	450	2.4/5	–	(70)	(soft)
DECT	1.152	$1.88 - 1.9$	10	75	soft

[*] Per spatial stream
[**] Lower bound due to CSMA-CA channel access
[***] Seamless HO possible but not guaranteed

1) WirelessHART

This technology was developed in order to extend existing HART standard with wireless capability. Based on 802.15.4, it provides a mesh network topology with deterministic TDMA channel access with fixed time slots. This way, latency of 10 ms can be achieved. Nevertheless, the latency can further increase due to multihop character of the network [7].

2) ISA 100.11a

This technology was developed to provide wireless capability for various number of fieldbuses such as Modbus or Profibus, but also HART. Due to this reason, ISA 100.11a became more flexible but also more complex as compared to WirelessHART. ISA 100.11a also utilises deterministic TDMA channel access, but the time slot duration is variable leading to latency of around 100ms [7].

WirelessHART as well as ISA 100.11a provide indoor range of ca. 30 m [8]. Due to multiconnectivity character of mesh networks, seamless HO is possible but cannot be guaranteed as single connectivity may appear.

C. 802.11 – WLAN

IEEE 802.11 defines a family of sub-standards for wireless local area networks (WLANs) for high data rate communication with wide coverage area. This standard defines a set of communication protocols for licence-free bands of 2.4 GHz, 5 GHz and 60 GHz such as .11a/b/g/n/ac/ad. Besides, it also defines a number of amendments as for example .11e for Quality of Service (QoS).

For 2.4 GHz band, there are 13 overlapping channels with 20 MHz bandwidth each. However, only 3 channels are non-overlapping. The most recent standard at this frequency band is .11n. It provides techniques like antenna diversity with a Multiple Input Multiple Output (MIMO) for spatial multiplexing, Orthogonal Frequency Division Multiplexing (OFDM) as well as frame aggregation on MAC layer in order to improve the throughput. The standard also defines channel bonding technique making channel bandwidth of 40 MHz possible. Achievable gross data rate of a single spatial stream is 72.2 Mbps in 20 MHz channel and 144 Mbps in 40 MHz channel [9]. Data rate can be increased up to 600 Mbps by using 4x4-MIMO [9]. There are also improvements for 5 GHz band which are not considered here as they are surpassed by .11ac described below.

In 5 GHz band, 23 non-overlapping channels of 20 MHz bandwidth are available. As defined by .11ac, neighboured channels can be bonded into single channel with maximum bandwidth of 160 MHz. In such a channel, a single spatial stream and 8 spatial streams can achieve data rate of 866.6 Mbps and 6.933 Gbps, respectively [10]. To the best of our knowledge, current .11ac client devices are capable of up to 2x2 MIMO.

As shown by authors in [11], the best case latency for 802.11 systems may lie below 10 ms for idle channel. On the other hand, 802.11 uses carrier sense multiple access with collision avoidance (CSMA-CA) multiplexing method by means of distributed coordination function (DCF). Before transmission, any client senses channel activity. In case it is busy, the client delays the transmission by a random backoff time interval. In this manner, latency may increase

unpredictably due to delayed channel access, making DCF inacceptable for real-time communications [12]. Besides, the standard proposes an alternative channel access method by using point coordination function (PCF). It provides a contention-free period coordinated by the access point, so providing TDMA scheme by polling registered clients. Some of the drawbacks are unpredictable beacon delays and unknown transmission duration of polled stations, which results in delays for emerging latency-critical traffic. To the best of our knowledge, there exist no commercial devices supporting PCF scheme, with exception of proprietary IWLAN solution [13].

Aforementioned channel access schemes can be improved by introducing Quality of Service (QoS), as defined by .11e amendment. It defines hybrid coordination function (HCF), which consists of two channel access methods. One of them is Enhanced Distributed Channel Access (EDCA). It improves DCF by means of QoS-aware backoff intervals leading so to prioritization of traffic. EDCA is widely implemented in the hardware, but it is not suitable for real-time traffic. The other method, HCF Controlled Channel Access (HCCA), is an improvement of PCF, which also extends EDCA rules. Among others, it defines a method for flexible polling stations also during contention period as well as an advanced QoS support. Unfortunately, there are currently no devices available, which implement HCCA.

Another attempt to provide deterministic channel access for automation purposes is reported as real-time WiFi [14]. In contrast to polling-based approach, it introduces dynamically scheduled TDMA phase into WLAN traffic. The major advantages are reduced protocol overhead as well as improved deterministic behaviour.

WLAN supports communication range of around 70 m at 2.4 GHz band for indoor applications, in 5 GHz band, the range is around half of it [8]. The standard defines a client-driven hard handoff procedure. As shown by measurements in [15], HO may last for up to seconds in standard mode and around 50 ms using proprietary features. As during hard handoff no communication is possible, a delay of even 50 ms may be critical to some real-time applications.

A proprietary solution based on .11n standard, which is worth mentioning here, is IWLAN by Siemens [13]. Based on .11n, it can operate at both 2.4 GHz and 5 GHz frequency bands achieving gross data rate of 450 Mbps by means of 3x3 MIMO. The major feature of this technology is the support of PCF channel access, which makes IWLAN capable of real time traffic support. Unfortunately, no reliable numbers on achievable performance could be found in the literature.

D. DECT

Digital Enhanced Cordless Telecommunications (DECT) is a European standard for consumer cordless telephony defined by ETSI ETS 300 175. It uses licenced band of 1880 – 1900MHz, dividing it into 10 channels with bandwidth of 1.728MHz per channel. For channel access and duplexing, TDMA and TDD schemes are used, respectively. DECT supports maximum data rate of 1.152 Mbps per time communication channel [16]. Also, guaranteed latency of 10 ms can be achieved making the system capable of real time applications [3]. Furthermore, DECT provides indoor

communication range of 75 m [3]. Moreover, there is seamless handover procedure defined by the standard, prohibiting data loss and delays.

III. INDUSTRIAL USE CASES AND REQUIREMENTS

There are many emerging use cases which can help industry evolve to a new level while utilizing wireless communication. On-site support, remote live support, augmented reality manual, mobile and remote operation control, building automation and many more are just few examples. In fact, it is expected that with the proliferation of novel wireless technologies more and more industrial use cases will come up and will be implemented in real-world systems. Here, wireless communication represents an enabling technology for many key concepts of Industry 4.0 by providing the maximum degree of reconfigurability, flexibility, mobility, and ergonomics [17, 18]. To provide a better understanding, two generic use cases are described and analysed in more detail.

A. Augmented Reality

Augmented Reality (AR) is an emerging technology, which extends the physical world with virtual information [19]. In our work, head-mounted optical see-through devices are in focus. In a sustainable way, AR-enabled devices with wireless communication on-board will support workers while offering navigation, live documentation of their work, context-dependent assistance (e.g., remote live support), etc. In the latter use case, an operator has to wear a head-mounted AR device, which is able to record a video stream of the user's view – possibly along with other information, such as an audio stream, sensor data, etc. – and send it to a remote expert. The expert may be located anywhere and therefore may – in the most general case – only be reached via a wide-area network (WAN), such as the Internet. The latency for the video and audio streams shall not exceed 250 ms and 150 ms respectively [20]. According to the received data stream, the expert gives precise advices adding extra information aka annotations to the live stream. These annotations are shown in the operator's glasses at proper positions, so he can easily follow the instructions. An accurate positioning is required along with some complex AR computations. The latency requirements for AR algorithms are very strict in order to make sure that a loss of immersion and cyber sickness can be avoided. Since today's AR glasses lack powerful CPUs, the AR computations should be offloaded (e.g., by using mobile edge computing concepts) to a server [4]. The end-to-end latency, which includes the recording of a new image, its transfer to the server, the necessary AR computations (e.g., localization and rendering) and the transfer back to the client device, should not exceed 20 ms in the best and 70 ms in the worst case. In order to support future AR devices with 4K resolution and stereo cameras, data rates up to 500 Mbps (in case of H.264 encoding) and up to 6.6 Gbps (in case of uncompressed video stream) shall be supported. The jitter of the video transmission shall not exceed 20 ms [21].

B. Mobile Control Panel

As another use case, operation of a production unit via a mobile control panel (MCP) provides higher flexibility and comfort for operators and can lead to increased productivity

and lower costs compared to currently existing wired solutions. A critical element of such a MCP is the availability of safety-critical control elements, such as an emergency stop or an enabling switch, which have to operate according to the strict safety standards also over a wireless link.

The functions of an operation panel can vary from configuring basic settings, such as operation speed, to a precise step-by-step execution control in jogging mode. Therefore, the requirements for particular applications can vary significantly. A possible message flow of an example safety application can be as follows. First, the MCP has to be activated when the user registers with the authentication data. After the MCP is paired with the machine, the configuration interface is loaded so that the user can view and change the settings on the touch screen. The control unit cyclically reads the status of the emergency stop button on the MCP and expects an answer within a defined time window (watch-dog time). In case the emergency button is pushed, the control unit stops the machine according to safety requirements. For a typical fieldbus system, the cyclic traffic of I/O signals and safety-critical applications will require a cycle time of 4–8 ms (time from emergency stop to action of the robot control less than 20 ms), jitter less than 50% of cycle time, data rate at least 1 Mbps, packet error rate less than 10^{-8} and data packet size of 40-250 Bytes as defined by EN IEC 61784-3-3. Furthermore, the safety-critical functions on the MCP shall support Safety Integrity Level (SIL) class 3 as defined in EN IEC 62061, SIL 3 as defined in DIN EN 61508, Cat. 4 and performance level "e" as defined in EN ISO 13849-1.

Additionally, by knowing the location of a user, three types of safety zones can be identified with different operation modes and features. In case of the enabling switch application on a MCP, the location of the MCP within a certain safety zone around the critical part of the associated machine with an accuracy of less than 10 cm must be provided every 30 ms. The handover latency observed by the safety function at the terminal shall not exceed 50 ms, and ideally should be below 30 ms.

Fig. 1 shows a radar chart for the AR and MCP use cases addressing the most relevant metrics and specifying a set of minimal and maximal requirements for a system. The range of requirements has to be considered here, since some requirements depend also on final system design.

From the security point of view, systems utilizing wireless connection are more open for potential attacks. In order to
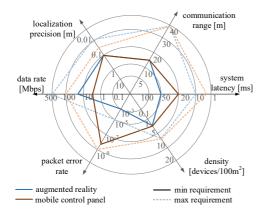
ensure safety of workers, availability and integrity of production machinery, confidentiality of personal and production data, the following requirements must be met. First, well-established baseline security mechanisms such as WPA2 must be applied on all air interfaces. A mutual authentication of all entities is required. The system should support the user defined security level SL1 as specified in IEC 62443. The system shall be able to detect potential jammers [22]. The used cryptographic ciphers shall be commonly considered to be secure and be expected to remain secure for the next 15 years. This list can vary for different types of applications and can be further extended.

IV. SYSTEM CONCEPT

Detailed consideration of requirements provided in Section III shows, that wireless communication plays one of the major roles in the realization of industrial HMI applications. Nevertheless, there are more requirements, which play key role in the realization of aforementioned use cases. Among them are precise in- and outdoor localization, IT-security or flexibility of the whole system. Due to this reason, our goal is not only to provide new wireless technology in order to fulfil industrial requirements. Rather, we aim for a complete system, which is able to provide a platform for novel applications in HMI field.

In order to do this, we propose an architecture as shown in Figure 2. Thus, to provide flexibility and scalability into the system, we propose to organise the whole industrial network in form of logical cells. They can, but do not have to, follow the internal factory structure such as production cells. Any cell provides one or more wireless access points so as to connect mobile client into the network. Furthermore, every cell contains a number of logical servers which control and provide access for clients to the core functionalities. Those are *Localisation*, *Security* and *Safety*. Due to the network complexity, we provide also further functionality of *Network Management*. These functionalities can be extended by some added functionalities such as very precise image based camera pose tracking for augmented reality applications. On the global level, this server structure is mirrored once again in order to provide coordination between cells or to manage incoming WAN activities as for instance remote expert connection.

An inherent part of the system described above is still the wireless communication system. As described in Section III, HMI applications have heterogeneous requirements on the underlying communication system due to their variety. On the one hand, mobile operation of machines requires moderate data rate but low latency and deterministic behaviour of the communication. Here, systems such as Bluetooth, WirelessHART or DECT perform very close to the requirements, but suffer reliability. On the other hand, high

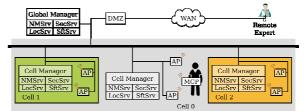Fig. 1. Radar chart with some major requirements

Fig. 2. Architecture of proposed communication system

data are required by AR-applications. Here, WLAN standard seems to be more appropriate solution, but it suffers deterministic latency and seamless HO support.

As one can easily recognise, none of the current wireless solutions is perfectly fitting to the requirements, so that a new communication approach is needed. As the most HMI applications are less critical to latency as compared to closed loop applications but are greedy to data rate, we propose to further improve WLAN concept to allow the new wireless solution to fulfil the requirements as described by the next section.

V. ENABLING TECHNOLOGIES

In this section, we present an overview on the emerging technologies, which will help to adjust the proposed system to industrial requirements.

A. 60 GHz-Communication

The above mentioned communication scenarios require a huge data throughput on the wireless link, reaching up to several Gbps for the AR use case scenario as described in Section III. The 60 GHz band is a very good candidate for frequency band selection, since it provides a large amount of unlicensed bandwidth. Worldwide, a bandwidth of 5 GHz is available [23], while the bandwidth in Europe and other countries reaches up to 9 GHz, thus enabling data rates above 10 Gbps with simple modulation. Simple modulation schemes allow implementing very fast and therefore low-latency baseband processing algorithms, fulfilling the given requirements. In combination with the multi-band, high free space loss and line-of-sight necessity can be overcome.

B. Multiband connectivity

A multiband approach is necessary to improve reliability for the use cases such as safety application as illustrated in Section III. As mentioned above, the 60 GHz-technology cannot be used for highly reliable communication due to its weak signal propagation properties. Hence, it makes the usage of 2.4 GHz or 5 GHz link necessary. In this case, a multiband coordinator on the MAC layer is required. Thus, it is reasonable to combine the three bands in order to increase the reliability of communication. Based on the QoS requirements, the multiband scheduler manages the traffic to use appropriate band according to the mapping table. For instance, safety critical traffic can use both 2.4 and 5 GHz simultaneously to increase reliability, whereas the high data rate video stream should be forwarded through 60 GHz link. Besides, in case of the link drop at 60 GHz, switching to e.g. 5 GHz backup band is possible so as to maintain connectivity.

C. PHY Layer - Flexible GFDM Waveform

Flexible radio waveforms adapting the PHY layer configuration to different propagation channel conditions and communication scenarios are another option to improve the robustness of the radio transmission and to increase its efficiency. Here, Generalized Frequency Division Multiplexing (GFDM) [24] is selected as promising example for a flexible and adaptive waveform since it is able to address several of the above defined requirements.

GFDM is a flexible block filtered multi-carrier modulation scheme. Using subcarrier filtering enables significant reduction of out-of-band (OOB) emissions, the control of peak-to-average power ratio (PAPR) and a dynamic allocation of radio resources. Benefiting from a flexible pulse shaping in time and frequency, GFDM is robust against channel impairments and inter-user interference (IUI) in multi-user context caused by time and frequency misalignments between users [25].

Using GFDM, communication channels and subcarriers can be placed more tightly without introducing adjacent channel or subchannel interference, respectively.

In addition, an improvement of throughput can be achieved due to the fact that with GFDM and its better OOB radiation more (data) subcarriers can placed in one symbol compared to OFDM considering a fixed channel bandwidth. For example, in 802.11ac, 56 subcarriers (in total; incl. 52 data and 4 pilot subcarriers) per OFDM symbol are used for transmission over a channel of 20 MHz bandwidth. Due to the significantly lower OOB radiation, more subcarriers can be used in GFDM. By increasing the number of subcarriers e.g. to 60 in a 20 MHz channel, a throughput gain of approximately 8% can be achieved in comparison to OFDM with same modulation and coding scheme (MCS). An additional gain in throughput can be achieved by using a CP block-wise instead of symbol-wise. For instance, for a typical .11ac configuration with 3.2 μs FFT and 0.8 μs CP duration, a throughput gain of 16% could be attained for a GFDM resource block of 5 subsymbols. Besides, adding only a single CP for one GFDM block instead of prefixing each subsymbol also reduces the overall GFDM symbol duration, which helps to reduce the impact of PHY layer to transmission latency. For low latency, GFDM symbols can be demodulated independently and the GFDM frame duration can be configured to operate with an integer fraction of a 1-ms latency budget. Due to its flexibility, GFDM is also backward compatible to 802.11 legacy modes and can be configured to operate in OFDM or single-carrier modulation schemes.

Overall, using a new and flexible waveform, in particular GFDM, allow improving latency, spectral efficiency and robustness of the transmission.

D. Channel Access

To guarantee the strict latency requirement for the use cases described in Section III, an improved channel access strategy is mandatory. The channel access mechanism along with frame aggregation helps to determine the time to access channel and to improve the throughput requirements by optimizing MAC protocol overhead, respectively.

Even though most WLAN deployments rely on DCF, it doesn't support QoS. This problem is solved through the prioritization of traffic. On the other hand, the problems with PCF, mentioned in Section II, are solved using HCCA by assigning transmit opportunity and scheduling polled station transmission [26]. It also can guarantee the delay requirement of cyclic traffic such as safety in industries by polling station at any time including in the contention period. For an isolated infrastructure mode, the delay of EDCA increases with the number of stations [26]. Thus, adapting the parameter set is required. On the other hand, in multi-AP architecture with no

resource sharing, the delay of HCCA can increase. These can be solved either using a controlled WLAN environment or having central controller that manages resource sharing among hybrid coordinators.

E. Localization

Proper localization of mobile devices is a must for use cases like augmented reality and safety zones as described in Section III. While outdoor positioning systems are quite common (e.g. Global Navigation Satellite Systems – GNSS) and precise, they suffer from bad indoor coverage. For indoor localization, the currently favoured methods are based on measuring the received signal strength (RSS), on RSS fingerprinting or on direct time-of-flight (ToF) measurements; using UWB or WLAN technology [27]. UWB provides a very good ranging resolution, but it requires additional hardware compared to WLAN solutions. Therefore, it is beneficial to use the already deployed communication hardware for radio ranging and localization. With the proposed system concept, the high bandwidth of the 60GHz band is not only used for high-data rate communication, but also for distance measurements. With 2 GHz of bandwidth, a sub-centimeter precision comparable to UWB can be reached [28], fulfilling the requirements for safety zones without adding additional hardware.

F. Mobile Edge Computing

A new level of factory automation requires processing of vast amount of data, complex orchestration of cyber-physical systems, and coordination of computation as well as communication resources in real-time [17]. Mobile edge computing (MEC) is a promising approach to achieve the low latencies required by many industrial applications. MEC employs resource rich edge servers that are placed close to end devices and assist them in executing computation intensive tasks. The core element of MEC is the cognitive management entity that, among variety of tasks, ensures the advanced resource planning. To fulfil high industry requirements mentioned in Section III, MEC enables further important techniques besides effective resource allocation and offloading [18]. These include caching, mobility support, service migration, data prioritization, etc. Many aspects of MEC are still in a very early development phase and are expected to continue evolving over the next decade.

VI. CONCLUSION

There is a number of emerging use cases for human-machine interaction, which could benefit from the usage of wireless communication. Due to their stringent requirements on data rate, latency, reliability and some other aspects, current communication systems cannot fulfil the demands of those applications. In this paper, we analysed the requirements needed by the communication systems. Moreover, we proposed a whole system concept based on WLAN standard, which makes it possible to abolish current limitations and introduce a wireless communication system into HMI application field. Our future work is on the realisation of the concepts, which have been described in this paper and also integrating all of them into a working system in order to prove those concepts.

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