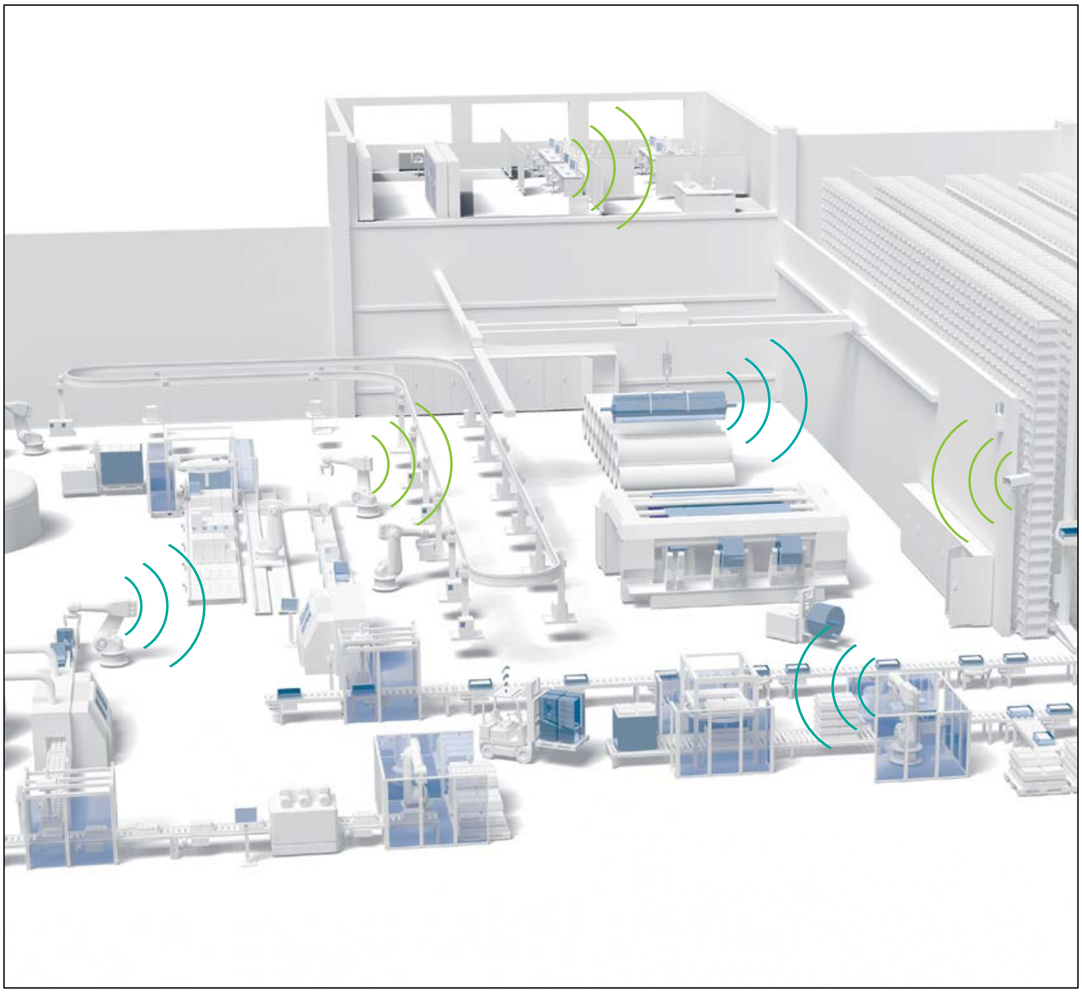

White paper

Coexistence mechanisms of Factory Line Bluetooth for interference-free parallel operation with wireless LAN

Authors:

Andreas Pape, Dipl.-Phys.
Industrial Electronics
apape@phoenixcontact.com

Jürgen Weczerek, Dipl.-Ing. (FH)
Industrial Electronics
jweczerek@phoenixcontact.com

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1 Bluetooth for industrial use

Bluetooth is a wireless technology that is in common usage in the consumer sector. In actual fact, more Bluetooth chipsets are currently sold each year than WLAN ones; this is primarily due to the use of this technology in cell phones, headsets, etc. The basic technology is standardized in IEEE standard 802.15.1. Beyond the standard, the Bluetooth Special Interest Group (SIG), the association for manufacturers of Bluetooth chipsets and devices, defines various application profiles. These include voice transmission, serial communication, and Ethernet transmission in what are known as personal area networks (PAN).

For industrial communication, this technology is particularly interesting for several reasons:

1. Communication is established time-synchronized with the medium and is therefore very similar to the way wired fieldbuses work with respect to deterministics.
2. Chipsets and ultimately the devices that use them are standardized and can therefore be used globally and manufactured at an affordable price.
3. The way Bluetooth works means that it is not necessary to configure wireless parameters to establish a wireless connection. This is, for example, of particular importance for applications in machine building. Imagine, for example, if an end customer operating several machines of the same type in a single hall had to adapt the wireless solutions individually in each machine before they could be put into operation. In most cases, that would be unacceptable.
4. Application profiles such as SPP (serial communication) or PAN (transparent Ethernet) can be used on a one-to-one basis in industrial applications for a multitude of control and configuration tasks.
5. Bluetooth uses just a small bandwidth of 1 MHz in the frequency spectrum. This enables a number of systems to be operated in parallel without interference. It also leads to a limited net transmission speed, which however, with approx. 700 kbps, is still high enough for several automation applications. As a result, a more optimum utilization of the small frequency spectrum available for license-free wireless transmission is achieved.
6. Bluetooth has proved to be a highly robust technology, particularly when employed in industrial environments with large amounts of steel and reinforced concrete. This is because it is able to skillfully deal with effects such as multipath fading in highly reflective environments.

2 Frequency response

Owing to its channel width of 1 MHz and the frequency hopping method that is implemented with time slots of 625 µs, Bluetooth allows a very high density of wireless networks to operate in parallel without causing interference. This is not just important for cell phone applications, for example at airports or similar locations where lots of people wish to use headsets independently of one another to make phone calls, but is also a key requirement for industrial communication.

The situation gets more complicated, however, when Bluetooth needs to coexist without interference alongside systems that operate with fixed frequencies, as is the case for WLAN (see Figure 1). Whereas WLAN splits the 2.4 GHz ISM (industrial, scientific, medicine) band into 13 channels and requires a bandwidth of approx. 20 MHz for each WLAN system, Bluetooth splits the same band into 79 channels.

If interference occurs on a Bluetooth channel because a WLAN is also operating there, Bluetooth still has the option to "frequency hop" to the next time slot to work with a completely different frequency, which may be outside the WLAN spectrum. Due to the static frequency it uses, WLAN does not have this option.

Whether interference to Bluetooth or WLAN occurs or not doesn't just depend on the frequency alone. The signal levels of whatever is causing the interference and whether both systems are sending data simultaneously also play their part. For example, WLAN is very good at dealing with narrow-band elements causing interference provided their signal levels do not exceed a certain signal-to-noise ratio in relation to the WLAN signal.

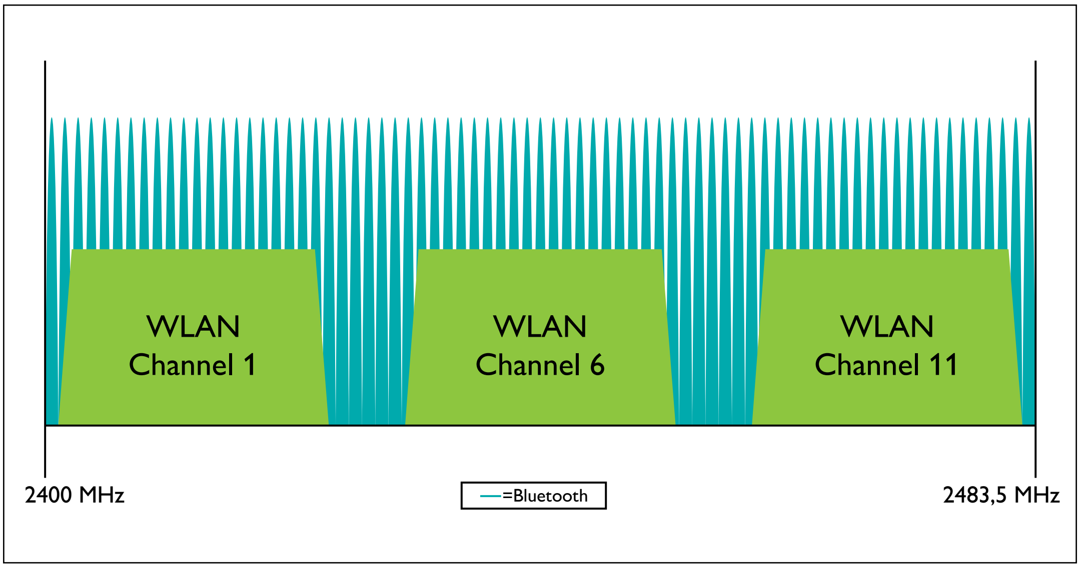

Figure 1
Use of the license-free 2.4 GHz ISM band by Bluetooth and WLAN

However, particularly as the simultaneous occurrence of WLAN and Bluetooth networks both in consumer and office environments as well as in industrial communication is the rule rather than the exception, as of specification 1.2, Bluetooth has integrated an automatic coexistence mechanism, known as adaptive frequency hopping (AFH).

This gave Bluetooth radios the option of no longer using channels perceived as being “poor” for communication (see [1] and [2]). The hopping sequence and decision regarding which channels should not be used are determined by the master of the Bluetooth network. For Phoenix Contact's wireless I/O system, this is always what is known as the base station.

In line with [1] and [2], the master now has three options for deciding to remove a frequency in the list of possible Bluetooth channels (known as the channel map) from the hopping sequence:

1. Individual measurements:
   These can either be passive (evaluation of reception levels [RSSI = received signal strength indication] on channels if the BT network itself is not currently sending anything) or active. If the channel is active, an evaluation is carried out of the link quality that correlates with the bit error rate for the transmission per Bluetooth channel in its own network.
2. Measurements and reports from slaves:
   Based on demands from slaves, the master can also decide to block a channel for communication in the network. Just like the master, the slave can obtain this information from its own measurements, but it has to send a corresponding report to the master to request it to block the channel, as only the master is allowed to carry out network coordination tasks.
3. The third option is for the Bluetooth master to receive the information for its channel map from its host system (prompt: Set-AFH-channel-classification-command). The standard allows for certain Bluetooth channels to be configured for removal from the hopping sequence; this is also known as channel skipping or blacklisting.

The standard for Bluetooth specifies these options, but it does not state that all mechanisms have to be implemented. In particular, it does not specify any limit values based on which channels could be classified as “poor” and therefore no longer used, for example due to RSSI limit values or in the event that bit error rates are exceeded.

This and the fact that Bluetooth also only has one chance to detect another frequency user such as a WLAN system when this is also sending data, means that it is only possible to detect other systems from a certain network load. As a rule of thumb, experience with Bluetooth chipsets from various manufacturers has shown that, in the case of WLAN coexistence, the WLAN must have a network load of at least 10% to ensure that it is reliably detected by Bluetooth and that this happens across its entire frequency range.

In consumer end devices in particular, option three specified above cannot generally be configured for users, even though the chipsets have to have the corresponding commands implemented in accordance with the standard.

Nevertheless, devices from Phoenix Contact have the option to be configured manually by the user. There are however a few conditions attached to this configuration; these result from international regulations for frequency hopping systems:

1. Bluetooth must use a minimum of 20 channels for communication, and these must be distributed across the entire band used.
2. The American regulatory body FCC also demands that frequency management is used exclusively for the purposes of preventing interference by wireless systems in line with other wireless standards (e.g., WLAN in line with IEEE 802.11). It must not be used to increase the system density of frequency hoppers of the same standard (see [3]).

Figure 2 shows the use of the 2.4 GHz band by three independent WLAN systems on WLAN channels 1, 6, and 11, as well as a Bluetooth system in the remaining spaces in between. For each WLAN channel, the Bluetooth system spares 19 Bluetooth channels, i.e., 19 MHz, meaning that 23 channels are still available for Bluetooth communication.

With the Bluetooth systems from Phoenix Contact, this ensures that there is optimum coexistence between other frequency users of the 2.4 GHz band and particularly between WLAN systems as the result of clear frequency separation. As the mechanism is strictly Bluetooth-compliant, the frequency response can accordingly also be influenced in exactly the same way by Bluetooth devices from other manufacturers that do not support manual configuration but whose devices at least correspond to Bluetooth standard 1.2: They are operated as a slave to a master from Phoenix Contact, such as a Bluetooth access point.

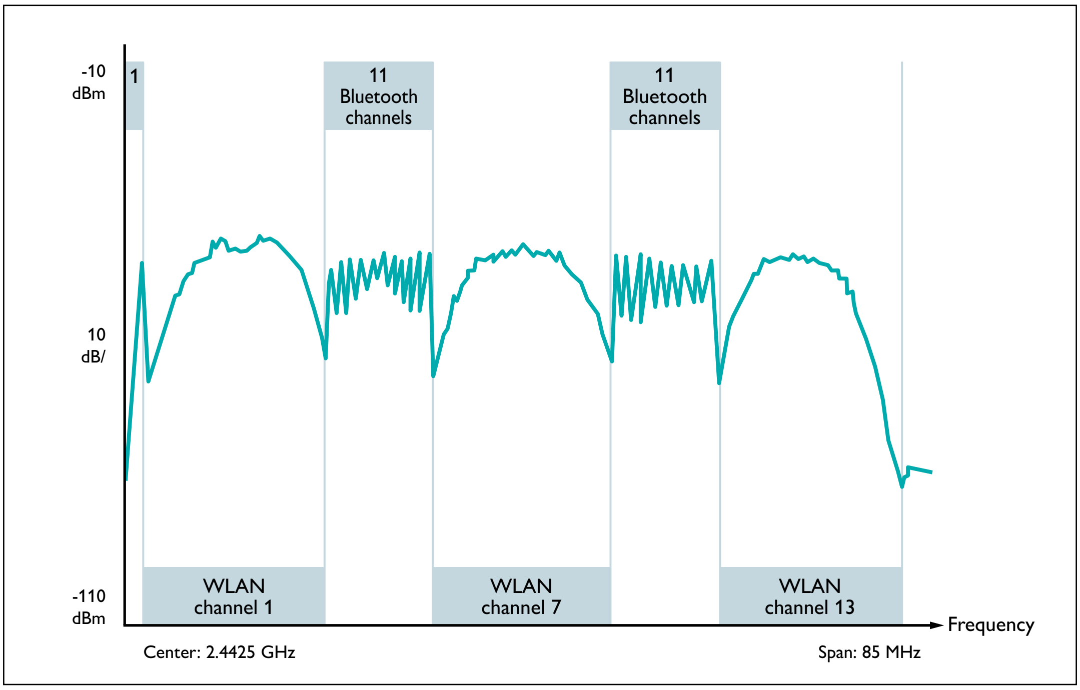

Figure 2

Spectrum measured when using three WLAN channels and one Bluetooth system with manual channel skipping/blacklisting

3 Transmission power

A further parameter that results in an improvement to the coexistence between different wireless solutions or between wireless solutions using the same technology is transmission power. As a general rule, it is possible to set an individual transmission power at chip level for virtually all wireless solutions, irrespective of their technology.

Whereas in consumer and office solutions a static transmission power is often to be found that can no longer be configured by the user, for automation technology applications it makes sense to make this adjustable. The basic principle to follow is that the transmission power should be set to be as large as necessary but as small as possible.

Beyond static, adjustable transmission power, Bluetooth makes use of individual, automatic closed-loop power control. This means that Bluetooth from version 1.2 automatically reduces the transmission power to the lowest possible level. The transmission power set on Phoenix Contact devices simply defines the maximum possible transmission power. Particularly in the case of applications with short ranges of just a few meters, this will be significantly decreased by several dB via the control mechanism. Although the original idea behind implementing this technology for Bluetooth was to prolong the battery life of cell phones, it also provides further advantages with respect to coexistence and system density that are not to be underestimated.

Bluetooth makes a distinction between three different transmission power classes:

Class	Max. transmission power [dBm]	Max. transmission power [mW]
1	+20	100
2	+4	2.5
3	0	1

Whereas cell phones mainly use class 3 radios with a typical range of 10 meters, class 1 radios allow communication distances of well over 100 meters outdoors and for antennas within line-of-sight range. For indoor applications, class 2 radios still achieve ranges of 30 meters or more, which is perfectly sufficient for typical machine or production cell dimensions.

Whereas closed-loop power control is optional for classes 2 and 3, it is a mandatory requirement for class 1 radios. It is for this reason that Phoenix Contact always uses radios that are compliant with class 1 even if they are to be operated in devices with a lower maximum transmission power.

4 Establishing a connection – inquiry and paging

For Bluetooth, there are two operating phases where it is necessary to pay special attention to coexistence between other wireless systems: These are the search for nearby and connection-ready Bluetooth devices (inquiry) and the actual establishing of a Bluetooth communication connection (paging).

As the devices are inherently not integrated into a Bluetooth network in these conditions, the AFH mechanisms cannot take effect at this point. In addition, a device that wants to connect to another participant must first synchronize its frequency hopping sequence with that of its requested connection partner.

To do this, the devices use only 32 of their 79 Bluetooth channels. The device, which for example, wants to establish a connection, i.e., a paging process, hops through these channels at double the hopping frequency (3200 hops instead of the usual 1600 hops per second) sending connection requests simultaneously. To ensure that the receiver is able to accept a new connection in addition to any connection to a Bluetooth network that may already be present, this device has to "listen" to its paging channels at certain intervals. This is known as a page scan.

Whereas a scanning device does not have any influence on nearby wireless participants, as it has only a passive reception response, the active paging device can have a huge influence. The Bluetooth standard defines a series of parameters that determine the time response for paging and inquiry. These include the page scan interval, page scan window, inquiry scan interval, and interlaced scan.

Phoenix Contact uses special parameters for page and inquiry or page scan and inquiry scan which enable a very good compromise to be reached between the quick establishment of a connection and good WLAN compatibility: This is known as low emission mode (LEM).

Devices that accept a connection frequently use page or inquiry scan for a short period of time, whereas the device that establishes the connection only sends data for a very short period (approx. 100 ms), then takes an extended break until it establishes a connection again (approx. 3 s later, see Figure 3).

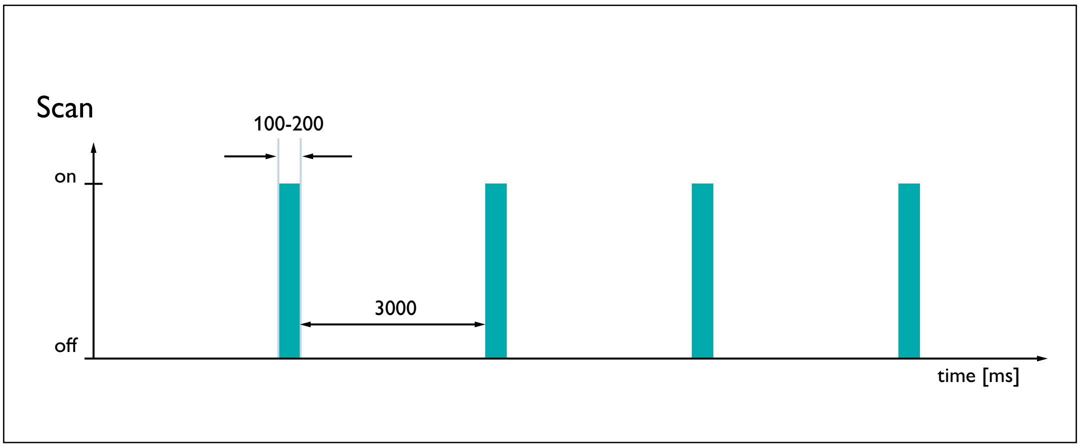

Figure 3
Paging for devices with low emission mode

Consumer devices, on the other hand, often use the strategy of paging as much as possible when operating with Bluetooth in order to establish a connection quickly. This can be seen in Figure 4.

It shows the paging process of a standard Bluetooth USB stick (graph on left) with a spectrum analyzer compared against a wireless I/O device from Phoenix Contact with LEM (right). Please note that the graph shows transmission power (y axis) over time (x axis), not spectra.

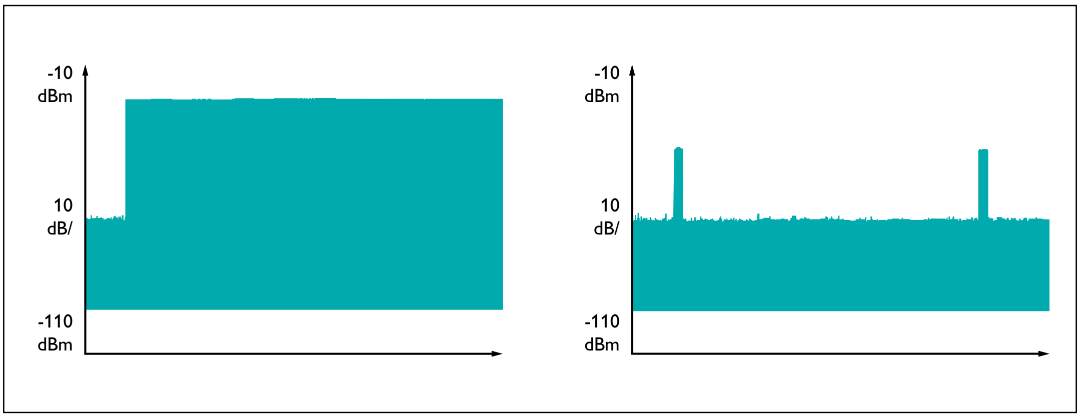

Figure 4

Comparison of a paging process for a Bluetooth USB stick without LEM (left) with a device from Phoenix Contact with LEM (right)

You can see that the USB stick is permanently sending data, whereas the device in LEM only transmits short pulse packets and then gives other frequency users time to use the wireless medium.

To put it simply, low emission mode provides a time multiplex for the wireless medium, whereas the AFH mechanisms achieve a frequency multiplex. Frequency planning for Bluetooth, including for the paging and inquiry processes, is not provided for in the standard. The only option is therefore to reduce the time it takes for other frequency users to establish a connection.

Nevertheless, Phoenix Contact devices are also compliant with the standard in low emission mode, meaning that it is of course still possible to establish a connection to non-Phoenix Contact devices. In such cases, however, this can lead to longer connection times, particularly if the Phoenix Contact device is paging in LEM and the device in the page scan, i.e., the connection partner that is to accept the connection, does not support low emission mode.

For a WLAN system, the influence of a paging process with or without low emission mode is as shown in the two figures below.

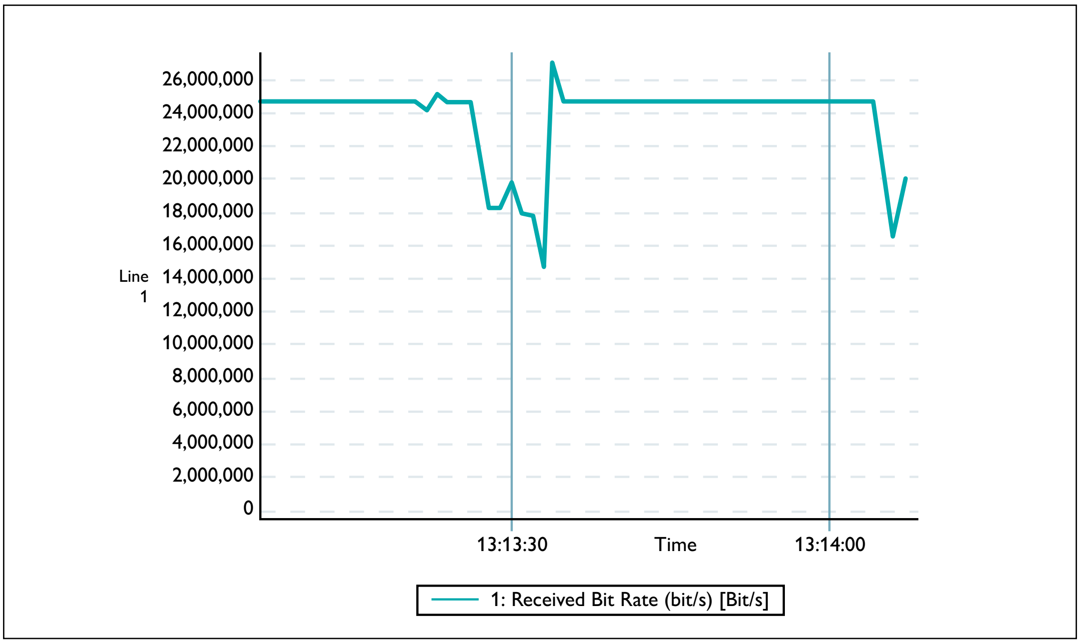

Figure 5
Influence of a paging process without LEM on the data throughput of a WLAN system

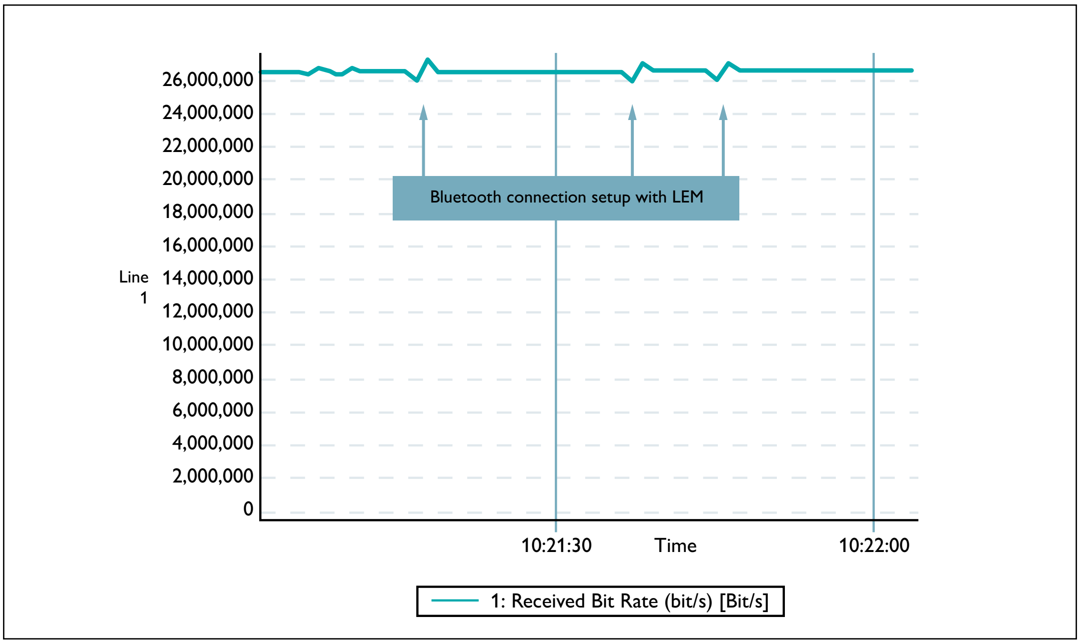

Figure 6
Residual influence of a Bluetooth system with LEM on the data throughput of a WLAN

The data throughput of a WLAN system was taken as an indicator of the influence of the WLAN in these measurements. 1500-byte packets with a net data rate of approx. 25 Mbps were transmitted via a WLAN system operating in 802.11g mode.

During a paging process without low emission mode, the WLAN data throughput dropped significantly. Depending on the paging configuration implemented by the device manufacturer, the result can be even worse and result in a complete standstill for the WLAN connection. With LEM, however, the influence of the paging process on the WLAN via the time multiplex of the media access is barely discernible.

5 Conclusion

Manual channel skipping or blacklisting as well as adjustable transmission power enable an optimum coexistence between different frequency users when Bluetooth solutions are running. In terms of establishing a connection too, where AFH and channel blacklisting are as yet unable to be effective for a specification-compliant Bluetooth implementation, the standard provides options for minimizing the residual wireless influence on other wireless systems based on the skilful choice of parameters (low emission mode).

6 Literature

[1] IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks Part 15.1: Wireless medium access control (MAC) and physical layer (PHY) specifications for wireless personal area networks (WPANs), 2005

[2] Specification of the Bluetooth system, Core Package 2.1 + EDR, July 2007

[3] FCC rules part 15 – Radio frequency devices, Section 15.247: Operation within the bands 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz, February 2006

PHOENIX CONTACT

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Markets within the automotive industry, renewable energy, and infrastructure are supported by means of consistent solution concepts, ranging from engineering and maintenance to training services, in line with specific needs. Product innovations and specific solutions for individual customer requirements are created in the development facilities at our sites in Germany, China, and the USA. Numerous patents emphasize the fact that many developments from Phoenix Contact are unique. Working closely with universities and scientific institutes, technologies of the future such as E-Mobility and environmental technologies are researched and transformed into marketable products, systems, and solutions.

PHOENIX CONTACT GmbH & Co. KG
32825 Blomberg, Germany
Phone: + 49 52 35 3-00
Fax: + 49 52 35 3-4 12 00
phoenixcontact.com