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Choosing the best wireless protocol for typical applications

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Abstract

This paper gives an overview of the existing wireless network standards with their main usage, used frequency band, modulation, transfer speed as well as features and limitations. The main focus on this paper is an assistance to choose the best fitting protocol for an application. Therefore some typical scenarios for applications are described and after a preselection based on the main usage, the wireless network standards are compared to find the best protocol for a given scenario. The scenarios are constructed that there is for every application an fitting scenario.

1 Introduction

Choosing the right wireless network standard is getting a challenge because of the high amount of standards which are also very similar. Research on these network standards is a very time consuming task. The wireless network standards are designed for different applications like industrial monitoring, health care, home automation or access control and alarm systems. Every application has different requirements on the communication system. Some need a very low latency where others need a high secure connection or a long battery life cycle. After an overview of the wireless network standards in Sect.~2 some typical applications for wireless networks are described in Sect.~3. Before the wireless protocols are compared for a scenario a preselection is done based on the most important property of the scenario.

2 List of protocol standards

This section gives a short overview of the available state of the art wireless sensor network protocols with properties of their physical layer. If there are some extra features or limitations on a protocol then these are also listed in this section.

2.1 IEEE 802.15.4

The IEEE 802.15.4 Standard [3] defines the physical layer and the medium access control layer. Many popular wireless sensor network protocols are based on this IEEE standard. All RF transmission are made in the ISM (Industrial, Scientific and Medical) radio band, the frequencies of the ISM band vary by region. The used frequencies of the ISM band by this standard with their limitation:

- 868-868.6 Mhz (Europe)
- 902-928 Mhz (North America)
- 2400-2483.5 Mhz (worldwide)
- 3100-10600 Mhz (UWB varies by region)

The IEEE 802.15.4 standard specifies the physical layer and the medium access control layer, the most important properties for wireless networks like the frequency range, transfer rate and the modulation. There are a few versions of this specification available 802.15.4 [3], 802.15.4-2006 [5] and 802.15.4a-2007 [4] where the standard IEEE 802.15.4 is mostly called 802.15.4-2003. The main difference of IEEE 802.15.4 and IEEE 802.15.4-2006 is the added ASK and O-QPSK modulation which enables a higher transfer rate at the lower frequencies. One reason to use this standard is, that there was some work done on coexistence with other networks, specially in the 2.4 GHz frequency and the 802.11 standard.
The specified frequencies, modulation and the resulting transfer rates varies by region as they are all within the ISM band.

- 868-868.6 Mhz, BPSK, 20 kbps
- 868-868.6 Mhz, ASK, 250 kbps (802.15.4-2006)
- 868-868.6 Mhz, O-QPSK, 250 kbps (802.15.4-2006)
- 902-928 Mhz, BPSK, 40 kbps
- 902-928 Mhz, ASK, 250 kbps (802.15.4-2006)
- 902-928 Mhz, O-QPSK, 250 kbps (802.15.4-2006)
- 2400-2483.5 Mhz, O-QPSK, 250 kbps

The IEEE 802.15.4a standard is an addition to the IEEE 802.15.4 and adds some more frequencies of the ISM band and another modulation for the 2.45 GHz frequencies. Ultra Wide Band (UWB) uses 16 channels in three UWB bands which are at 250 to 750 MHz, 3.244 to 4.742 GHz and 5.944 to 10.234 GHz. The range of free frequencies between 3 to 10 GHz varies by region. Within the 2.4 GHz band are 14 overlapping chirp spread specturm (CSS) channels added to the IEEE 802.15.4 standard.

2.1.1 ZigBee

ZigBee [1] is a low-cost and low-power wireless sensor network which is used in energy management and efficiency, health care, home and building automation and industrial automation. The ZigBee protocol uses the 802.15.4 standard and operates in the 2.4 GHz frequency range with 250 kbps. There are also a few ZigBee modules available which were optimized for the lower frequencies in Europe and North America. The low duty cycle, which is lower than 0.15%, makes ZigBee to a low power communication, as the node can be in a sleep mode the most time. The maximum number of nodes in the network is 1024 with a range up to 200 meter. There are ZigBee modules available which have a range of more then 1000 m, these modules operate with the maximum allowed transmit power of 10 mW. ZigBee can use 128 bit AES encryption.

2.1.2 6LoWPAN

6LoWPAN is a acronym of IPv6 over Low power Wireless Personal Area Networks. This protocol is designed to be used for energy management, home and building automation. This proptocol operates only in the 2.4 GHz frequency range with 250 kbps transfer rate. There is no encryption defined by the 6LoWPAN protocol, the range is up to 200 meter and the maximum nodes is limited to 100 per network. This limitation exists for one channel and can be extended using wired backbones to connect subnets.

2.1.3 Wireless HART

Wireless HART [13] is an industrial standard for process monitoring and regulation. Wireless HART is based on the IEEE 802.15.4-2006 standard and uses the free frequencies around 2.4 Ghz. To prevent interference from other applications Wireless HART uses frequency hopping with blacklisting of bad channels and has a high reliability in challenging environments. The range is up to 250 meter with an 128 bit AES encryption.

2.1.4 ISA 100

ISA 100 [14] is also based on the IEEE 802.15.4-2006 standard and uses only the 2.4 GHz frequency band with frequency hopping to prevent interference from other wireless networks. The main application for ISA 100 is industrial automation. One of the important properties of ISA 100 is the low latency or fast response time of 100 ms. ISA 100 has an interoperability with a wide range of wired communication protocols, including HART, Profibus, Foundation Fieldbus and Device Net.

2.1.5 WiMi

The two WiMi [16] standards, WiMi and WiMi P2P are based on IEEE 802.15.4-2003 and operate in the 2.45 GHz frequency. This Wireless sensor network uses a proprietary protocol from Microchip and works on their micro controllers. The protocol is optimized for short messages which are used for communication with sensors. WiMi and WiMi P2P have a range up to 125 meter indoor and up to 550 meter outdoor. The communication can be encrypted with 32, 64 or 128 bit AES. There is a limit of 1024 nodes for WiMi networks.

2.1.6 SimpliciTI

SimpliciTI [20] is a proprietary wireless network from Texas Instruments. It is based on the IEEE 802.15.4 standard and works in the 433 MHz, 868 MHz and the 915 MHz frequencies with up to 300 kbps at a range of 100 meter.

2.2 KNX

KNX [15] is a home and building automation communication system which is based on international standard ISO/IEC14543-3, european standards CENELEC EN50090 and CEN EN 13321-1 and 13321-2, Chinese standard GB/Z 20965 and ANSI/ASHRAE 135. It operates at a frequency of 868.3 MHz with FSK modulation and reaches a transfer rate of 16.384 kbps. KNX nodes with additional connectors to power line are available to enable communication between nodes which are not within RF range or the RF communication is blocked by objects. The KNX standard is not free of charge.

2.3 EnOcean

EnOcean [12] is a sensor network which works in the frequencies of 868 MHz for europe and 315 MHz for North America. The transmit range goes up to 30 meter in buildings and up to 300 meter outdoor. The range can be extended by repeaters. Batteryless EnOcean modules with energy harvesting are available which reduce the life cycle cost as they are maintenance free. EnOcean has patents for energy harvesting wireless sensor networks. Encryption is not included but EnOcean is prepairing rolling code encryption for their nodes.

2.4 Dash7

Dash7 [11] is a low power long range wireless network technology based on the ISO 18000-7 Standard and uses a

RF frequency of 433.92 MHz and a transfer rate up to 20 kbps. The range can be adjustet from 100 to 10 kilometer with a dynamically adjustable datarate of 28 kbps to 200 kbps. The ISO Standard is not available for free.

2.5 WISA

WISA [9] is an abbreviation for Wireless Interface for Sensor and Actuators which was developed by ABB in 2003. It is based on the IEEE 802.15.1 physical standard and operates at a frequency of 2.4 GHz with a transfer rate of 1 Mbps. Because of the deterministic time behavior of WISA it is real time capable, also the frequency hopping to prevent interference of other networks has a deterministic behavior. The limitation of WISA are 360 devices per cell and a maximum of 120 devices per master. WISA has two systems which can be combined, WISA-COM which is only the wireless communication and WISA-POWER which is communication and power supply via RF similar to RFID and anti theft devices.

2.6 ANT, ANT+

ANT [17] is a wireless protocol and a silicon solution which focus on sport and wellness but also on home and industrial automation and logistics/goods tracking. This wireless network operates in the 2.4 GHz frequencies. The protocol is optimized for short package transmission but allows also a burst transfer with up to 20 kbps. The maximum number of devices per channel is limited to 65533 where multiple channels can share the same frequency.

2.7 WiMax

WiMax is based on the standard IEEE 802.16 [6] and is intended for wireless metropolitan area networks. The range is different for fixed stations, where it can go up to 50 km and mobile devices with 5 to 15 km. WiMAx operates at frequencies between 2.5 GHz to 5.8 GHz with a transfer rate of 40 Mbps.

2.8 ONE-NET

ONE-NET [18] operates in the free sub-G frequencies, for Europe there are 3 Channels at 865 MHz to 868 MHz and for North America 25 Channels at 902 MHz to 928 MHz. The Transferrate can be adjusted between 38.4 kbps and 230.4 kbps with a range up to 100 meter indoor and up to 500 meter outdoor. The network topology can be star, peer to peer and also multi-hop. For data security an 128 bit encryption can be used. The maximum number of nodes are limited to 4096 for ONE-NET.

2.9 Z-Wave

Z-Wave [21] is focused on wireless remote control and home automation and operates in the 868 MHZ frequency. The range is up to 30 meter at a maximum transfer rate of 40 kbps and maximum of 232 nodes within a network.

2.10 Insteon

Insteon [19] operates at the 904 MHz with a data rate of 13.165 kbps and a burst data rate of 2880 bps. The devices have a range of 45 m line of sight as addition it can be connected via powerline. The protocol is optimized for short messages and is used for home automation, alarm systems and access control. There are 2^{24} unique IDs available and the devices can be grouped with a maximum of 256 group members per group. At the moment there is no encryption implemented, but rolling code, managed key or public key algorithms might be added soon.

2.11 Bluetooth

Bluetooth [10] works in the 2.4 GHz ISM band and uses frequency hopping. With a data rate up to 3 Mbps and maximum range of 100 m. Bluetooth is meant to be a cable replacement. Bluetooth uses profiles for the communication. Each application type which can use Bluetooth has its own profile. Wibree merged with Bluetooth and is ULP Bluetooth (Ultra Low Power Bluetooth) which is in the Bluetooth standard Core V4.

2.12 WiFi

WiFi [2] is a good etablished netwok for WPAN (Wireless Personal Area Network) it is based on the IEEE 802.11 standards and operates in the 2.45 GHz frequency range. The transfer rate goes up to 54 Mbps for 802.11g and up to 150 Mbps for 802.11n.

2.13 NFC

NFC [8] is based on the standard ISO/IEC 18092:2004, using inductive coupled devices at a center frequency of 13.56 MHz. The data rate is up to 424 kbps and the range is with a few meters short compared to the wireless sensor networks.

2.14 RuBee

RuBee is based on the IEEE 1902.1 [7] standard and is used as tagging system. The range can be a few inches up to 50 feet. The RuBee specification meets the MIL STD 810G standard and uses a base frequency of 131 kHz (2^{17} Hz) with a transfer rate of 1024 Hz (2^{10} Hz).

3 Typical scenarios for wireless applications

With the high amount of wireless protocols it is a time consuming task to find the best protocol for an application.

After extracting the requirements for the wireless communication of an application, it can be sorted into typical scenarios. In the following sections some typical scenarios will be specified and a preselection from the above list of wireless protocols will be done based on the needed main features. This list will be further examined for the scenario to find the best fitting protocols.

3.1 Low power sensors

This scenario is for sensors which transmit some values with longer phases in between where they are inactive. During these phases the transceiver can switch into a mode which uses lowest energy. Most transceivers offer a sleep mode to safe energy, which is best to use during these inactive phases. The duration can varies on the application and can vary from seconds, minutes to hours. The longer the sleep phase lasts the more important is the power consumption during the sleep phase. Such nodes can operate with batteries or harvest the needed energy from their environment (like small solar panels). When the node can harvest the energy, the maintenence costs is independent from the power consumption, but on all other cases, specially when the node operates with batteries, it is important to have a very low power consumption, as the cost to change the batteries will be more then the battery itself. For these scenarios the latency and data rate are not important and can be of lower perfromance.

To compare all available network standards it would be a high effort to collect all the data, so a preselection was necessary. The compared values are power consumption values from transceivers only. The power consumption of the micro controller depends very high on the micro controller itself and on the operating frequency. For EnOcean and Z-Wave are no transceiver values available, these values include the power consumption of a low power micro controller. The consumption values are calculated from typical current consumption in sleep, transmit and receive modes of data sheets. To have compareable values for the receive and transmit modes, the transmit output power of 0 dBm and a higher sensitivity mode for longer range is compared.

Table 1: Power usage of preselected wireless networks

	power consumption		
Protokoll	sleep	transmit	receive
IEEE 802.15.4	0.06 μW	36.9 mW	34.8 mW
ANT	1.8 μW	39 mW	33.9 mW
ONE-NET	0.3 μW	63 mW	57.9 mW
EnOcean	0.6 μW	99 mW	72 mW
Z-Wave	8.25 μW	75.9 mW	120 mW
WiMax	33.6 μW	224 mW	358 mW
Bluetooth	330 μW	215 mW	215 mW
WiFi	6600 μW	835 mW	1550 mW

As all IEEE 802.15.4 protocols can use the same transceiver, there is one representative value for the IEEE 802.15.4 protocols including ZigBee, 6LoWPAN Wireless HART, ISA 100 and the proprietere protocols WiMi and SimpliciTI. Tab.~1 shows that IEEE 802.15.4, ANT and ONE-NET have the most power efficient transceivers, where the IEEE 802.15.4 transceiver has the best power saving mode. Depending on the sleep duration ONE-NET and EnOcean can perform better on the power consumption then an ANT sollution.

3.2 Industrial applications

Low latency and a reliable comunication are the most important requirements on a wireless sensor network for industrial automation and process monitoring and regulation. As interference generates higher latency when packets needed to be retransmitted and in case of an interference of longer duration the packet might not be able to be transmitted which makes a wireless network vulnerable against other wireless network protocols using the same frequency. Most of the wireless sensor networks operate in the 2.4 GHz band of the ISM frequencies therefore it is neccessary to have a strategie against interference and a preselection on this feature can be done. Bluetooth, Wireless HART, ISA 100 and WISA have some methods to avoid disturbance from other networks.

The preselected wireless network protocols have a common function to avoid interference, they all use frequency hopping. This methodology changes the frequency / channel on a regular base in a known order. A channel which is used from a different network has only for the duration while this channel is used impact to the sensor network.

- Wireless HART
  - frequency hopping
  - frequency blacklisting
- ISA 100
  - frequency hopping
  - low latency
- WISA
  - frequency hopping
  - deterministic behaviour
  - wireless power
- Bluetooth
  - frequency hopping

All of the protocols above are allready used in industrial applications. All of them use frequency hopping to have as low interference from other wireless networks as possible, which is neccessary to have a reliable communication with the nodes. Some unique features of the protocols are blacklisting from Wireless hart, which disables a channel if there is too much noise within the channel frequency. ISA 100 has low latency. WISA has wireless power which is harvested from a radio frequency which is sent from a power station close to the sensors. WISA is also real time cabable because of a deterministic behaviour. Depending on the needed features for an application it will be neccessary to check other requirements of the communication.

3.3 Home and building automation

Home and building automation is built up with a bigger network of nodes. For offices there can be a requirement of a few thousand nodes while the home automation might not reach more then hundred. For these scenario there is a tradeoff of the range versus amount of nodes within the network.
Building automation requires a bigger network of nodes on a bigger area, therefore the number of nodes and the range are the more important propperties. There can be a requirement of a few thousand nodes for an office building, while a home network will mostly have less then 100 nodes. A preselection is done on the main application for sensor networks for home and office applications.

Table 2: maximum number of devices and range of wireless network protocols

Protocol	max. number of devices	range indoor	range outdoor
Dash7	2^{32}	10 m	10 km
ONE-NET	4096	100 m	500 m
EnOcean	>4000	30 m	300 m
Z-Wave	232	30 m	300 m
WiFi n	2^{32}	70 m	250 m
Zigbee	1024	30 m	200 m
6LoWPAN	100	30 m	200 m
WiFi g	2^{32}	40 m	140 m
WiMi	1024	125 m	550 m
Bluetooth	2^{16}	10 m	100 m
Insteon	2^{24}	n.a.	45 m

In Tab.~2 are the values for the maximum number of nodes and the ranges of the wireless protocol shown, the ranges are for indoor and outdoor, where outdoor means unobstructed line of sight. The maximum number which is given as address length are no limitations of the protocol but the performance will drop down with a higher channel utilisation. Some network protocols like 6LoWPAN, Dash7, Insteon and WiFi, are designed to communicate also with a wired protocol to extend range or build subnets to lower the utilisation of the channel.
From the above table are only a few protocols capable of handling more then a few thousand nodes either directly or via subnets. ZigBee, 6LoWPAN, EnOcean, Dash7, ONE-NET and Insteon can be used for building automation of bigger office buildings. The other protocols are designed for smaller networks like home automation.

3.4 Data transferrate

Wireless protocols are also used as cable replacement, in this case the data transferrate is most important while the range can be a few meters. The scenario is a multimedia environment with a few devices which need a higher data transfer rate. Wireless protocols for multimedia connections focus on this scenario and require a short range but a high data transfer rate to be able to handle the data traffic for audio and video streams. in Tab.~3 is a preselection listed which is based on higher bandwidth and to compare it with sensor networks the IEEE 802.15.4 standard is shown as reference to the wireless sensor networks which operate within a close range of data transfer rate and range.

Table 3: speed and range of wireless network protocols

Protocol	data transfer rate	range
IEEE 802.15.3a	480 Mbps	3 m
IEEE 802.11.g	150 Mbps	70 m
IEEE 802.11.n	54 Mbps	40 m
WiMax	40 Mbps	15 km
Bluetooth	24 Mbps	10 m
IEEE 802.15.4	250 kbps	30 m

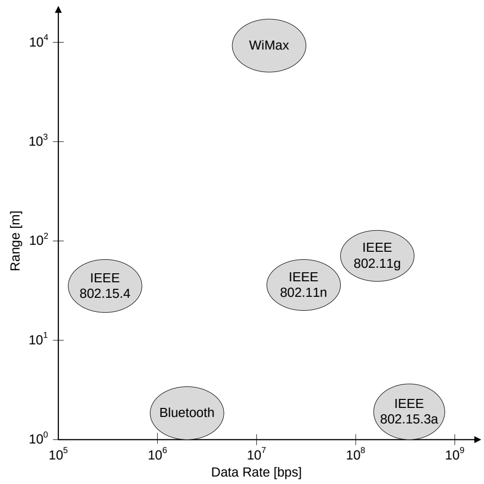

Figure 1: speed and range of wireless network protocols

There is allways a trade off between data transfer rate, speed and power consumption. In Fig.~1 are a few protocols shown. For wireless sensor networks is only IEEE 802.15.4 shown as most of them are based on this standard and operate within a close range of range and data transfer rate. WiMax, WiFi (n and g) and IEEE 802.15.3a have a higher power consumption for a higher bandwidth compared to the wireless sensor networks and Bluetooth which were designed as low power networks. The trade off between range and data transfer rate can be seen on Fig.~1 for both, the low power networks and the high bandwidth networks. Depending on the environment the wireless networks cant operate within full range with their full bandwidth, therefore most protocols support lower data rate to extend their range.

4 Conclusion

This paper gives an overview of the existing wireless protocols with their advantages for some typical application. The typical applications where choosen to cover mostly all possible applications. Some applications might be in-between of two scenarios and therefore it is necessary to make some further research to find the best fitting protocol for the requirements. There are some compareable properties which make it easy to find the best protocol for a scenario like the power consumption or the transfer rate, while some other scenarios require to find the best protocol with a trade-off like between data transfer rate versus range. This work gives only an overview with a base to choose the right protocol for an application. The best wireless protocol does not exists as it depends too much on the environment and specification.

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