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12. WIRELESS CONNECTIVITY STANDARDS FOR INTERNET OF THINGS DEVICES IN SMART CITIES

12.1. Mobile communication systems

Publicly available wireless connectivity in cities is provided by cellular network systems, the history of which begins in 1979, when the analog mobile telephony system was launched in Japan (NTT network, Nippon Telegraph and Telephone). During this period, for example, the Scandinavian NTT system (Nordic Mobile Telephone, 1981) and the North American AMPS (Advanced Mobile Phone System, 1983) were established. Today all these systems are classified as 1G (1st Generation) systems which, despite general similarities, were created based on separate regional standards.

The next generation, 2G systems, are digital systems, but still based on independent standards. The North American D-AMPS standard was created in 1990 and it was implemented three years later. In Europe, in 1991, the GSM (Global System for Mobile Communications) system was established. In the later process of the mentioned systems development, the equipment manufacturers and standardization organizations around the world recognized the need of unification and in 1998 the 3GPP organization (the 3rd Generation Partnership Project) was established. Already under the banner of this organization, standards for packet data transmission called 2.5G were established, such as GPRS (General Packet Radio Service, 2000, made by ETSI, the European Telecommunications Standards Institute) and EDGE (Enhanced Data rates for GSM Evolution, 2003, compliant with the requirements of IMT-2000 issued by ITU, the International Telecommunication Union).

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The 3G systems are following the requirements in technical specification IMT-2000[4], which was released in 2000, but had been developed since 1992. The first commercial launch of the 3G cellular network was in 2001 in Japan. The specificity of 3G systems, compared to previous generations, is the separation of the data communication subsystem (packet switching) within the core network outside the area of the voice communication (circuit switching). The UMTS (Universal Mobile Telecommunications System) and CDMA2000 (Code-Division Multiple Access) standards included in the 3G network define the broadband Internet access services. The following generations of mobile standards maintain the trend of increasing available data rates.

Since the 4th generation (4G), mobile communication systems are changing from voice transmission systems, where an additional service is data transmission to packet data transmission systems, which offer voice communication as part of the available services. Transmission standard requirements under 4G have been described by ITU as part of the IMT-Advanced specification[5], and the 3GPP implementation is the LTE (Long Term Evolution) cellular system, first practically launched in Scandinavia in 2009. The available services, apart from the already mentioned packet-switched telephony, include mobile access to the World Wide Web, high-definition mobile TV, and video conferencing - broadband Internet access in general.

The direction of increasing the network performance is continued in the next generations of mobile wireless communication systems. Increasing access speed to network resources entails higher requirements for user equipment (UE) in terms of computational complexity, i.e. hardware resources and energy consumption. In the area of smart cities, however, the requirements leans toward the number of devices rather than the speed of communication. Internet of Things (IoT) devices in smart cities (e.g., weather stations, measurement sensors, home automation devices) typically send or receive small amounts of data at low speeds, but with constant access to the network. The specificity of requirements depending on the application (use cases) has been noticed by the standard developers (3GPP, ITU), which results in the creation of various options under a common umbrella, taking into account applications and mutual coexistence.

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[4] International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications – 2000 (IMT-2000), Recommendation ITU-R M.1457, Geneva, May 2000; International Telecommunication Union: Performance and quality of service requirements for International Mobile Telecommunications – 2000 (IMT-2000), Recommendation ITU-R M.1079, Geneva, May 2000.

[5] International Telecommunication Union: Requirements related to technical performance for IMT-Advanced radio interface(s), Report ITU-R M.2134, 2008; International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications – Advanced (IMT-Advanced), Recommendation ITU-R M.2012, Geneva, January 2012.

12.2. Internet of things devices

The IoT in the context of smart cities is used to define networking between devices like smart sensors, with software that enables to collect and process data, to connect with each other and exchange data via communication networks, in particular the worldwide Internet network. The word internet in the name suggests that these devices are connected to the public Internet network, although the actual requirement is only to be connected to any (local or wide) network and individually addressed allowing access to each device directly in order to send or receive the data.

On the consumer market, IoT technology is most often synonymous with products related to the concept of smart home, i.e. home automation devices that allow you to control lighting and heating, manage the home security system, control cameras and other devices in the household. Moving from the area of the smart home to the smart city, available sensors and controllers are used to manage the city by monitoring and controlling vehicle traffic, managing the availability of public transport, providing information related to the functioning of the city to both residents and tourists, or intelligent energy grid resource management. IoT device management is available from the level of mobile smartphones or via the web.

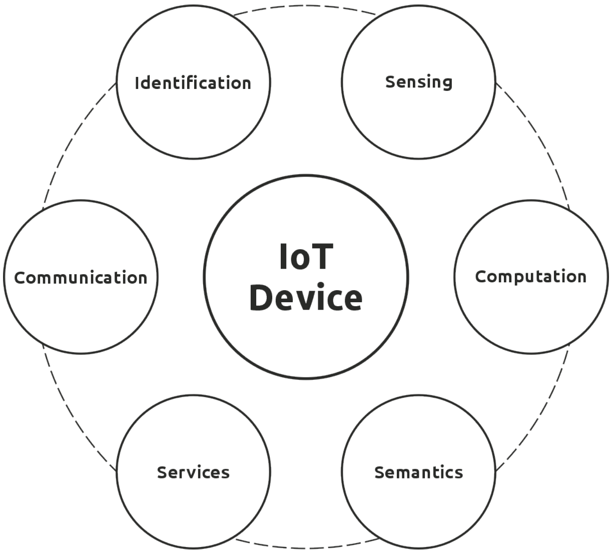

Fig. 12.1. Possible elements of the IoT device
Rys. 12.1. Możliwe komponenty urządzenia IoT

Figure 12.1 shows a general view on building blocks that an IoT device may contain[6]. IoT devices can be perceived as a computer systems that can identify each other based on

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[6] Abu-Rgheff M. A.: 5G Physical Layer Technologies, University of Plymouth, United Kingdom, Wiley-IEEE Press, 2019.

their parameters. When sensors are connected, they can be used to retrieve data from the environment. This data is transmitted over an available connection, usually wireless. The CPU (Central Processing Unit) that is the central unit of the IoT device can perform calculations based on the collected data and share the results through the implemented web services. When there are more devices, they can form a structure of connected objects that communicate with each other within a defined semantics. All these functions are assumed to be performed by a computer system with low computational resources and low energy demand, so the communication interface should also meet such assumptions.

The specific requirements for connectivity with IoT devices have already been noticed when defining 4G standards, where the application definitions appeared from the mainstream of developing networking participants. Today, the division clearly diversifying the parameters of wireless connectivity depending on the application is an integral part of the next generation (5G) evolution process. This diversity is presented in the form of the 5G triangle, which appeared in the ITU-R M.2083 recommendation[7] and defines the usage scenarios for 5G wireless systems.

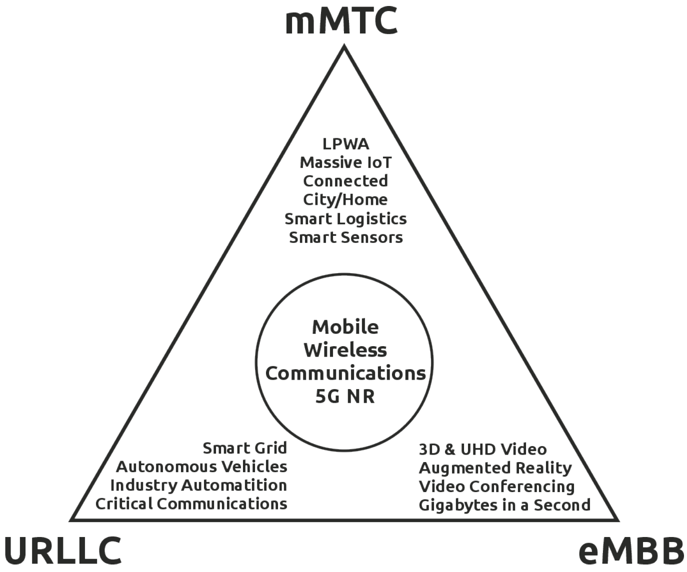

Fig. 12.2. Three main use cases of mobile wireless communications systems
Rys. 12.2. Trzy scenariusze zastosowań sieci mobilnych

The 5G triangle can be found in the literature in many versions, and Fig. 12.2 is one of the examples presenting the three main usage scenarios defined in the recommendations for wireless systems, for the 5G NR (5G New Radio) radio layer:

- eMBB (enhanced Mobile Broadband), focuses on providing higher bandwidths for use in mobile broadband communications, for example for UltraHD (Ultra High

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[7] International Telecommunication Union: IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond, Recommendation ITU-R M.2083, Geneva, September 2015.

Definition) video streaming, augmented reality or video conferencing (this is a continuation of the evolution of mobile networks towards higher bandwidths);

- mMTC (massive Machine Type Communications), designed for large numbers of low-power devices that regularly transmit small amounts of data, i.e. for massive Internet of Things deployments in smart home or smart cities;
- URLLC (Ultra Reliable Low Latency Communications), ideal for mission critical applications where network reliability and low latency are the most important, examples include autonomous cars and remote control or automation industrial processes.

Internet of Things devices, in the context of smart cities, are positioned in the mMTC category. As part of the city infrastructure, the need to install a large number of such devices is apparent today (monitoring of traffic, weather and environmental conditions, control of energy consumption and supervision of lighting systems, etc.), but the amount of data transmitted to and received from these devices will not be large, and there is no need to meet strict timing requirements. Within a smart city there will also be a place for devices that need wide bandwidth (urban monitoring) or high network reliability (autonomous vehicle traffic) but such usage models are not the subject of this chapter.

12.3. Massive machine type communications standards

The 3GPP organization, which currently defines wireless communication standards for mobile systems, publishes successive versions of them using subsequent Releases. Each Release assumes co-existence with previous Releases and defining a stable platform for new features implementation at a given point in development. New functionalities added in subsequent Releases can therefore be implemented within existing systems or systems in the design or implementation stage. Formally approved (frozen) standards are published by standardization organizations that are members of the 3GPP[8], such as ETSI, which maintains numbering in issued standards consistent with 3GPP technical specifications.

The basis for the development of 3GPP standards are technical recommendations issued by ITU-R (ITU Radiocommunication Sector). The requirements for fourth generation of mobile services (4G) were defined in the IMT-Advanced recommendation,

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[8] The 3rd Generation Partnership Project (3GPP): Official Publications, updated July 17, 2018, https://www.3gpp.org/specifications/63-official-publications.

the final version of which was published in 2012 (ITU-R M.2012[9]). As part of Release 8 of the 3GPP specification, the LTE standard was defined, which defines a new (compared to 3G) radio layer for mobile systems that is assumed to be compatible with the ITU-R recommendation. However, actual compliance with IMT-Advanced assumptions is not achieved by 3GPP specifications until Release 10, which is referred to as the LTE Advanced[10] standard. In 2021, ITU-R published the ITU-R M.2150 recommendation[11], which defines the next generation of mobile services (5G) created under the name IMT-2020. From the 3GPP side, the new generation of the radio interface (5G-NR) and other aspects of the new generation of mobile systems appear in the Release 15 of 2019, which is referred to as the first phase of 5G system implementation (The 5G System – Phase 1).

As of today, the last published version of the technical specifications 3GPP is Release 17 (5G). Previous Releases define the basis of 4G, then 5G systems as well as extensions, enhancements, or specific applications within the previously defined basis.

An example of such a specific application are the mMTC class devices, which require a radio interface in the technology generally referred to as Low Power Wide Area (LPWA). LPWA is designed to transmit small amounts of data at low rates and with low power requirements (providing long battery life), while having long range. The last of the conditions is not met by previously created systems of wireless devices using Bluetooth or ZigBee technologies for communication. The industry's needs related to range have been taken into account by such technologies as LoRaWAN or SigFox, which possess all the LPWA features. Unfortunately, these systems require their own network of transmitters (base stations) to operate, independent to mobile operators infrastructure. Therefore, it seems natural and economically viable to implement LPWA technology within publicity available mobile services. As part of the documents created by 3GPP, several LPWA-type standards were created, intended for IoT devices: LTE-M/LTE-MTC (Long-Term Evolution Machine Type Communication), NB-IoT (Narrowband-IoT) and EC-GSM-IoT (Extended Coverage-GSM-IoT). These technologies will be briefly described in the following subsections.

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[9] International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications – Advanced (IMT-Advanced), Recommendation ITU-R M.2012, Geneva, January 2012.

[10] Dahlman E., Parkvall S., Skold J.: 4G: LTE/LTE-Advanced for Mobile Broadband, Academic Press, London, United Kingdom, 2011.

[11] International Telecommunication Union: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications – 2020 (IMT-2020), Recommendation ITU-R M.2150, Geneva, February 2021.

12.4. LTE-M (EMTC)

The name LTE-M, or LTE-MTC, is a term used in industry and refers to machine-type devices communications over LTE networks (Long Term Evolution for Machine-Type Communications). Release 12 of the 3GPP specifications defines a low-cost (LC) enhancement to the requirements (Machine Type Communications enhancements): MTCe/LC-LTE[12]. The defined parameters function under the notion of the user equipment category Cat-0. Transmission in the full LTE bandwidth is assumed, i.e. 20 MHz, at rates up to 1 Mbps using a single-antenna system (SISO, Single-Input Single-Output). Optionally, the transmission can be carried out in Half-Duplex mode.

The focus on IoT devices has been enhanced in Release 13. Requirements for IoT devices regarding the transmitter power, battery life (10 years on a 5 Wh battery with a transmission of up to 200 bytes a day), transmission coverage and the number of devices in a given area (1 million per 1 square km) have been defined[13]. These requirements generally define ultra-low complexity and low-cost devices. The technical specification introduces devices of the M1 category and the appropriate LTE-M Cat-M1 operating mode. This mode is similar to defined for Cat-0 devices, the main difference is the operating bandwidth, which has been set to constant value 1.4 MHz. The bandwidth reduction enables significant energy consumption reduction. Theoretically achieved transmission speeds still reach 1Mbps in Full Duplex mode, but in Half Duplex mode it is about 300 kbps. Transmission standards for LTE-M class devices defined in a limited band are also referred to as eMTC (enhanced MTC).

The value of 1.4 MHz is formally the smallest value supported by the LTE system (more specifically Legacy LTE) and refers to 6 adjacent Physical Resource Blocks (PRBs) of 12 subcarriers with 15 kHz spacing in each, which sums to 1.08 MHz, giving with guard bands the total of 1.4 MHz. In contrast, usually the base station uses a wider channel (20 MHz) because, as mentioned earlier, the primary purpose of building LTE networks is to increase the speed performance, which is proportional to the bandwidth. Regardless of the channel bandwidth, around the center frequency using only 6 PRBs, a synchronization sequence (Primary Synchronization Signal – PSS and Secondary Synchronization Signal – SSS) is periodically transmitted, as well as a block of broadcast data (PBCH, Physical Broadcast Channel, containing MIB, Master Information Block) informing about the base station parameters. A device wishing to connect to the network based on this data, also in the 1.08 MHz core, sends a Random-Access Preamble as part

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[12] European Telecommunications Standards Institute: ETSI TS 122 368, Service requirements for Machine-Type Communications (MTC) – Stage 1 (3GPP TS 22.368 version 12.4.0 Release 12), Sophia-Antipolis, France, 2014.

[13] Ratasuk R., Mangalvedhe N., Bhatoolaul D. and Ghosh A.: LTE-M Evolution Towards 5G Massive MTC, 2017 IEEE Globecom Workshops (GC Wkshps), 2017, pp. 1–6.

of a random-access channel (PRACH Physical Random Access Channel), whose parameters can be deciphered from the base station identification data. The problem that needed to be solved is that further transmission in LTE is performed according to the information contained in the PDCCH (Physical Downlink Control Channel) control channel, which occupies the full bandwidth of the system, which would require increasing the complexity of the device to support a wider bandwidth.

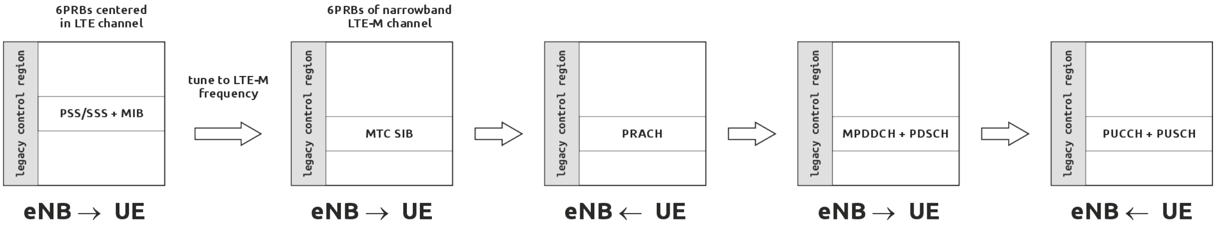

Fig. 12.3. Simplified eMTC Cat-M1 device to base station connection
Rys. 12.3. Schemat połączenia urządzenia Cat-M1 ze stacją bazową

The solution implemented in the specification is shown in Fig. 12.3. The base station, upon recognizing an eMTC device, assigns it a fixed center frequency for 6 PRBs (1.08MHz) and the MPDCCH (MTC Physical Downlink Control Channel) control channel is transmitted within this core band block. Frames directed to eMTC devices skip the first time slots (legacy LTE control region), so the devices using the full available bandwidth are not interfered with by transmissions for IoT devices.

Connecting the Cat-M1 device to the LTE network requires a base station software update to ensure that devices of this category can be properly supported. On the device side, the supported bandwidth is fixed and only tuning to the appropriate channel center frequency is required. Within the dedicated subband (channel group), the base station can support multiple IoT devices, managing the access within the dedicated group of channels as in the full LTE system, allocating channels and time slots within the available resources.

The coverage, in addition to receiver sensitivity, is increased by limiting the constellation size in OFDM (Orthogonal Frequency-Division Multiplexing) subchannels, depending on the mode of operation to 16-QAM (Quadrature Amplitude Modulation) or QPSK (Quadrature Phase-Shift Keying), and by allowing multiple data transmissions (repetitions). In addition, data aggregation within MPDCCH allows more devices to be addressed in terms of a single transmission block (accommodating more Controle Channel Elements, CCEs) or to better protect it against corruptions. Procedures that increase the coverage of devices, i.e. the possibility of correct reception at a lower signal power, on the other hand result in a reduction in the available transmission rate. Expectations of battery life are mainly achieved by the way Cat-M1 devices operate, such as infrequent power-ups to transmit a small amount of data and switching to deep sleep Power Saving Mode (PSM) after transmission period. In addition to the PSM mode, the eDRX (Extended/Enhanced Discontinuous Reception) mode is supported, where the device goes into sleep mode after agreeing its duration with the base station. If desired, the network stores data for the device for the predetermined period, after which the device wakes up and, after synchronization, performs the initiated transmission or returns to sleep mode.

Subsequent editions of 3GPP technical specifications include improvements related to LTE-M, including in particular the introduction of Cat-M2 devices operating in the 5 MHz band with transmission rates up to 4 Mbps. The functionality of the devices has been enhanced by improving positioning algorithms (based on signals from several base stations) or enabling voice transmission (VoLTE, Voice over LTE, service within Cat-M2 devices). However, these improvements differ from the mainstream applications of IoT devices, i.e. transmission of small amounts of data with low energy consumption, although they are still MTC class devices that require networks with lower performance than available in LTE/LTE-Advanced systems.

12.5. NB-IOT

The 1 Mbps rates offered by Cat-M1 devices are far greater than the requirements of IoT devices. 3GPP Release 13 defines two other standards for devices of this type, the first being NB-IoT (Narrowband IoT). This technology focuses mainly on improving the coverage (also indoors), further reducing costs, prolonging battery life and increasing the number of connected devices (at least 50,000 per cell).

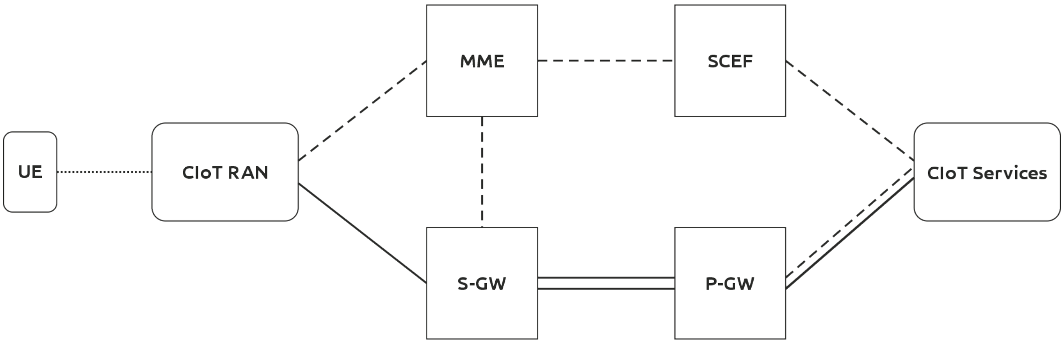

Fig. 12.4. Architecture of NB-IoT Network
Rys. 12.4. Architektura sieci NB-IoT

NB-IoT is based on known technologies, but presents a new perspective of the solutions. Within the 3GPP specification, an optimized architecture for IoT devices has been defined[14], named Cellular IoT (CIoT), which is shown in Fig. 12.4. The most important thing is that for IoT devices, an independent structure (at least virtually) has been created within the network resources to support them in the scope of CIoT services. This structure is similar to LTE architecture. Data to and from IoT devices can be sent, as in the LTE network, via S-GW (Serving Gateway) and P-GW (Packet Data Network Gateway) in the form of IP packets (Data Path, continuous line in Fig. 12.4) or as part of control data transmission (Control Path, dashed line). The second option is possible due to the small amount of data that is transmitted by IoT devices. When the data is not IP packets, it is routed to the main server via the SCEF (Service Capability Exposure Function). The MME (Mobility Management Entity) is responsible for device authentication and session management. By design, the NB-IoT network does not support mobility and handover, but the network remembers the parameters negotiated during the connection establishment and it is possible to resume them. The resume option only requires new encryption keys to be established, making the time required to reconnect to the network after coming out of the sleep state much shorter.

The similarities to LTE networks concern not only the network structure, but also the radio layer. The concept is based on an assumption that the transmission in the NB-IoT network is carried out in the narrow, 180 kHz band, in Half-Duplex mode, with the use of a single antenna (it lowers the cost of the UE). The maximum connection speed is below 200 kbps, but after activating the mechanisms for coverage enhancements, the actual rates are even lower. This 180 kHz band can be placed either on a released GSM channel (mode: Standalone), or on one of the LTE system sub-channels, occupying a single PRB (mode: In-Band), or within a frequency band that is a guard band for the LTE system (mode: Guard-Band) as shown in Fig. 12.5. An additional requirement is that the center of the channel must be in the 100 kHz grid (with a maximum spacing of 7.5 kHz to this raster), which in the case of In-Band mode is fulfilled only for selected channels of the LTE system.

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[14] Buurman B., Kamruzzaman J., Karmakar G. and Islam S.: Low-Power Wide-Area Networks: Design Goals, Architecture, Suitability to Use Cases and Research Challenges, in IEEE Access, vol. 8, pp. 17179–17220, 2020; Ahmadi S.: 5G NR: Architecture, Technology, Implementation, and Operation of 3GPP New Radio Standards, Academic Press, London, United Kingdom, 2019; European Telecommunications Standards Institute: ETSI TS 136 104, Base Station (BS) radio transmission and reception (3GPP TS 36.104 version 14.3.0 Release 14), Sophia-Antipolis, France, 2017.

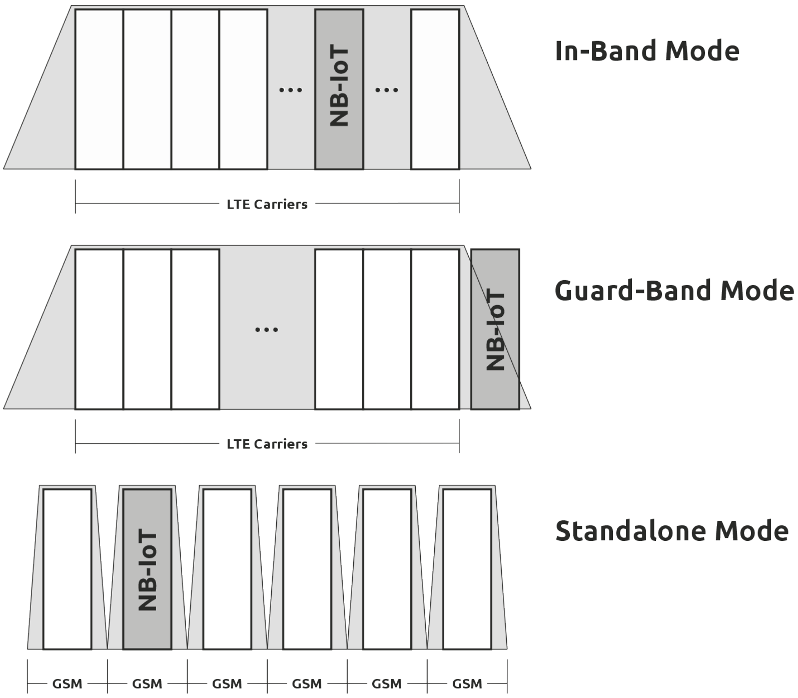

Fig. 12.5. Operation modes for NB-IoT communication
Rys. 12.5. Tryby pracy NB-IoT

From the base station (eNB, Evolved Node B) side, the transmission is carried out with QPSK modulated OFDM on 12 subcarriers with 15 kHz spacing, which corresponds to the structure of a single PRB in LTE networks. In the time domain, as in the LTE system, a full 10 ms frame consists of 10 subframes, each of 14 OFDM symbols. Since control data is sent on the first symbols of the subframe in LTE, the actual transmission in NB-IoT takes place on the last 11 symbols, without interfering with the in-band operation of the LTE system. Since in the LTE system, control data is sent on the first 2–3 symbols of the subframe, the actual transmission in NB-IoT takes place on the last 11 symbols, without interfering the LTE system operation in the In-Band mode. Further similarities to LTE concern the second layer, i.e. the frame structure, and the frame names have been supplemented with the prefix Narrowband. For example, NPSS and NSSS (Narrowband Primary/Secondary Synchronization Signal) frames are sent for synchronization. When the receiver is synchronized and identifies the base station data contained in the Narrowband Physical Broadcast Channel (NPBCH) frame, it can make its resource request in the NPRACH (Narrowband Physical Random-Access Channel) frame. Once the connection is established, the IoT device decodes the information sent by the transmitter by reading in the appropriate frames information about the location of the data sent to the device (NPDCCH, Narrowband Physical Downlik Control Channel, and NPDSCH, Narrowband Physical Downlink Shared Channel), or the space within the available resources for sending its data (NPUSCH, Narrowband Physical Uplink Shared Channel).

The transmission from the device (from the UE) can also, like from the eNB, take place on multiple carriers in multi-tone modulation mode (on 12, 6 or 3 carriers) with QPSK modulation on subchannels, but also single-tone modulation (BPSK, Binary Phase-Shift Keying, or QPSK) is possible in channels spaced every 15 kHz or every 3.7 5kHz. The latter possibility simplifies the design of the transmitting part of the UE device. The number of time slots allocated for transmission depends on the modulation mode offered by the device and is allocated to fit a similar amount of data, i.e. when using multiple channels, the device transmits shorter time.

The power consumption of the device is primarily reduced by autonomous transition to the Power-Saving Mode, when the device is unavailable until it wakes up and reconnects to the network. Additionally, an eDRX mode is available, in which the transition to sleep mode is coordinated with the host network.

12.6. EC-GSM-IOT

The last technology defined in the Release 13 related to IoT devices is EC-GSM--IoT[15]. This name appeared in the Release 13, which defined the previously described standards for IoT devices, but this time it does not refer to the new technology, but sanctions the existence on the market of IoT devices that use the GSM network, that is 2G or more precisely 2.5G, although some improvements were defined. The assumptions for creating this standard are similar to those previously described, namely increased coverage, 10 years of battery life, and support for a large number of devices within a single cell. The main motivation is to implement the technology by changing the software in the existing base stations of the GSM network, so that the change does not affect the devices currently using the network, allowing the interoperability of new and old UEs.

At the radio layer, the system is based on eGPRS (enhanced GPRS, also known as EDGE) transmission, which means that the bandwidth is 200 kHz and the achieved transmission rates can reach up to 70 kbps with GMSK modulation and up to 240 kbps with 8PSK modulation[16]. Extended coverage (EC) for EC-GSM devices is achieved by repetition of transmitted data, and the number of repetitions depends on the EC class,

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[15] Selvaraj R., Kuthadi V.M., Baskar S. et al.: Creating Security Modelling Framework Analysing in Internet of Things Using EC-GSM-IoT. Arab J Sci Eng, 2021.

[16] Selvaraj R., Kuthadi V.M., Baskar S. et al.: Creating Security Modelling Framework Analysing in Internet of Things Using EC-GSM-IoT. Arab J Sci Eng, 2021; European Telecommunications Standards Institute: ETSI TS 143 064, Overall description of the GPRS radio interface - Stage 2 (3GPP TS 43.064 version 14.3.0 Release 14), 2018.

which transfers to the coverage. The devices of the EC-GSM-IoT class are intended for the transmission of data and SMS messages, while the voice communication services are not available. In addition to modifications in the radio layer and frame formats for EC-GSM devices, the standard also introduces security system improvements related to mutual authentication, integrity protection, and enforcement of stronger encryption algorithms.

Since the intent was to be able to share resources between the new EC-GSM and traditional GSM devices, the base station after software upgrade (no hardware replacement is required) supports transmission of both types of devices by time multiplexing of data. As in the other systems defined in Release 13, increased battery life is achieved by the ability to enable deep sleep in PSM and as well as eDRX is supported.

12.7. Future of MMTC

All the described standards for IoT devices appeared simultaneously in the Release 13 of the 3GPP standards, which suggests that they are equally important for the developers of the technical specification, although a closer analysis shows slightly different application areas. Subsequent editions of the standards, including the Release 17 announced for this year (2022), contain extensions and enhancements for IoT-related standards. The IoT enhancements defined in Release 13 undergoes little modification, but additional functionality is added: additional services related to device positioning, adding support for mobility and handover between cells, or reducing latency and increasing available connection rates. The last is related to improvements in the physical layer, but marks the creation of a new class of devices that runs in parallel with the previously defined ones within the standard (Cat-M2, Cat-NB2). The 5G enhancements direction also includes many components aimed at power efficiency, like ultra-lean design and band partitioning.

Certain features are common to IoT devices, regardless of which of the described standards they use: they can work in battery mode for a long time, but to save energy they switch into sleep mode, during which they are unreachable, until they initiate a connection after wake up. The low transmission rates and high latency are the side features, but the cost of device production is low.

The EC-GSM-IoT devices are tied to the 2G network, which despite its old age is still in use, widely available and it allows access for older devices using GPRS.

The eMTC systems are related to LTE technology and are currently being deployed, while 5G NR systems are being implemented simultaneously[17]. On the one hand, NR systems are deployed in parallel with LTE in operation and LTE-M devices will be able to connect to the network as long as the operator has made this technology available as part of the 4G network. But according to 3GPP technical reports[18], there is no contraindication to transmit LTE-MTC data in the bandwidth of the NR system in FDM (Frequency-Division Multiplexing) mode under 5G NR, with subcarrier spacing (SCS) 15 kHz. Considering the frame formats of the 5G system (new synchronization frame, SS Block, Synchronization Signal Block – SSB), bands centered on certain subchannels should be defined in the standards that can transmit the 6 PRBs narrowband of the LTE Cat-M1 system in the band occupied by NR.

Looking forward, however, the most sensible choice for the future is NB-IoT. The implementation of the NB-IoT system on the part of the network operator requires the separation of resources related to the construction of Cellular Internet of Things (CIoT) subsystem. But from the side of the radio interface, we have the system that can use cellular infrastructure, while being independent of the technology of cellular network operation. In the currently defined operating modes, the transmitter can operate as part of 4G LTE resources or independently on one of the 2G GSM network channels. As for the cooperation with the 5G NR, it is required to transmit data related to NB-IoT within the physical resource blocks of this network. According to 3GPP technical report[19], NB-IoT system can be implemented in In-Band mode within 5G NR system with SCS 15 kHz. The NB-IoT device does not need information about the mode of operation of the eNodeB (4G) or gNodeB (Next-Generation Node B, 5G) it is connecting to. By detecting the sync signal on one of the supported channels (100 kHz raster) it always connects in the same way.

12.8. Conclusions

Following the recommendations of the ITU-R, the 3GPP organization developing standards for mobile systems as part of increasingly efficient interfaces for radio

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[17] Ahmadi S.: 5G NR: Architecture, Technology, Implementation, and Operation of 3GPP New Radio Standards, Academic Press, London, United Kingdom, 2019; Dahlman E., Parkvall S., Skold J.: 5G NR: The Next Generation Wireless Access Technology, Second Edition, Academic Press, London, United Kingdom, 2020.

[18] Alliance for Telecommunications Industry Solutions: ATIS.3GPP.37.823.V1600, Coexistence between LTE-MTC and NR (Release 16), 3GPP TR 37.823 V16.0.0, Valbonne, France, 2020.

[19] Alliance for Telecommunications Industry Solutions: ATIS.3GPP.37.824.V1600, Coexistence between NB-IoT and NR (Release 16), 3GPP TR 37.824 V16.0.0, Valbonne, France, 2020.

transmission, defines separate branches for various classes of devices, as shown in Figure 12.2, including the Internet of Things devices. The result of these activities are LPWAN class transmission standards, which operate over a large area and are suitable for implementation in smart cities. Unlike standards for local networks, it is easier to plan and implement a centralized system of access to devices available in a wide network. When choosing a standard for smart city infrastructure, it can be assumed that IoT devices supporting one of the mentioned cellular standards offer similar functionality. Looking forward, however, the most sensible choice for the future is NB-IoT.