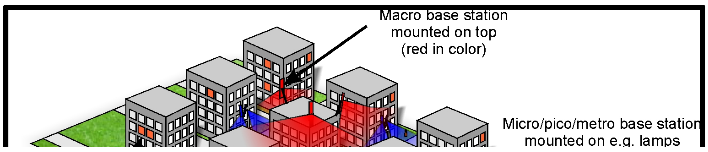
Waveform adaptation and small cells in white spacer, a talk on next generation telecommunications

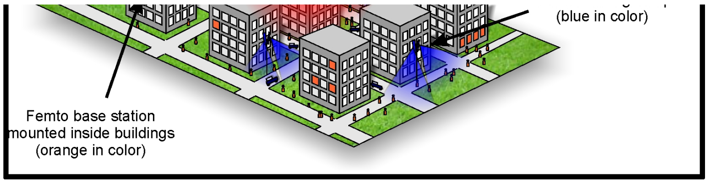
Everyone has to admit that the highly dynamic development of computer science and telecommunications, started a few decades ago, has revolutionized almost all aspects of our life. It is hard to imagine any branch of the broad economy, which will be able to operate effectively without fast and reliable access to various types of data. Analogous observations can be made in respect to education, science, health or any other services. And finally, social networks! These have changed irremediably the existence of the whole societies and smaller communities, becoming one of the key sources of information, a place for promotion and a virtual “agora” for discussion among people hidden by avatars. All of these opportunities are currently quite typical in numerous countries all over the world!

The guarantee of an effective functioning of people and companies (or other entities) in the digital and informative society has become possible due to the great achievements of broadly understood computer science. However, the design of advanced and global computer science solutions bases on the simultane-ous development of telecommunication systems and transmission techniques. In the era of high proliferation of mobile terminals (e.g., smarphones, smartwatches, tablets) it is important to concentrate also on the wireless part of data transmission. And indeed, each user of contemporary smartphone can decide to select one of a number of available wireless communication systems mounted in small device - just to mention such mostly popular solutions as Bluetooth, WiFi, WiMAX, UMTS, LTE and LTE-A, ZigBee, NFC, RFID. But, one cannot forget about the dedicated solutions for industry, transport, medicine or other branches of broad economy, such as TETRA or GSM-R.

OK, but if the variety of wireless systems is so big, then how can we imagine the further development of wireless communications? Is it necessary? And even more, if the available transmission speeds are high enough to guarantee trouble-free Internet surfing, why do we need the next, so-called fifth generation of cellular networks? The answer to this question is not so straight-forward. First, let us observe that every day more and more users send or download multimedia content from or to their mobile phones, and the expectations regarding the signal quality increase at least proportionally. And simply – the more high-quality multimedia content, the more spectrum requirements. On the other hand, the existence of the societies (people, companies, various entities) is more and more often dependent on the fast and reliable access to enormous amount of information (it is said about Big Data processing). And such an access has to be realized by means of… telecommunication systems, of course! Finally, one can observe the advent of Internet-of-Things, where the devices – not humans – will talk to each other to exchange data. Taking into account all of these observations it is envisaged that in twenty years from now LTE/LTE-A technologies will be no longer efficient. This is one of real needs for new cellular system development.

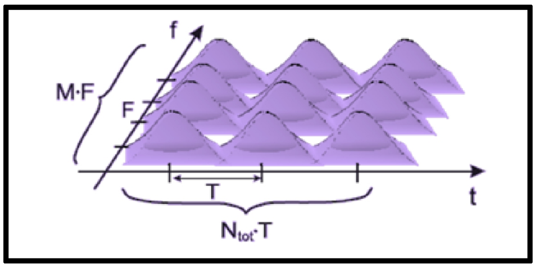
In that context, let us briefly analyze the issues related to frequency spectrum occupancy. It can be ob-served that the newer systems consume wider frequency fragments, for example in GSM one transmission channel had a width of 200 kHz, in UTMS- of 5 MHz, in WiFi 802.11n – up to 40 MHz, in LTE-A – even 100 MHz, and finally in WiFi 802.11ac the occupied band can be of 160 MHz! It simply means that the guarantee of higher data rates corresponds with higher “frequency consumption”. But the problem is that there is no such a spectrum in lower bands! The finding of wide frequency bands not assigned to any systems or not designed for any specific purposes is extremely hard. At the same time, numerous researches led in various places all over the world indicate that even up to 80% of spectrum is not utilized. For example, in the center of Poznan the measured spectrum occupancy in the frequency range between 75 to 3000 MHz is at the level of 20%! What does it mean? On the one side there is high need for wide vacant frequency band, on the other one can observe high spectrum underutilization due to static assignment of frequencies to certain telecommunication services. It is widely foreseen that this situation can be improved when the dynamic frequency allocation schemes will be implemented. The so called white spaces (i.e. the frequency gaps originally assigned to licensed user but not used at given time and location) could be used by unlicensed users unless the level of the interference induced to licensed user does not exceed some predefined level. It has been proved that very often the geographical area associates with the certain white space is rather small, thus it is natural to start data transmission in such an area only in the case when the physical distance between the transmitter and receiver is relatively small. And this observation brings us to the concept of using white spaces for the small-cells! But, what is the small-cell? It must be added that the transmit signal will be highly attenuated while propagating between the transmitter and receiver. For example, when the distance will increase two times, the signal can be attenuated even 10-16 times in typical urban and suburban environment, and up to 30-40 in dense urban areas! In that context it is well understood, why the reduction of the cell size is foreseen as a promising solution for rapidly increasing traffic in telecommunication networks. The radius of such a small cell can be as short as tens of meters or less. Such small base station will severe the user in one room (similarly to WiFi routers) or can be deployed on street lamps. Such a scenario is presented in figure below, where one can observe the macro cells (mounted on rooftop), micro/pico cells (placed on lamps) and femtocells (deployed inside the buildings).





Let us come back to white spaces now. It seems natural that white spaces could be considered in the context of small cells. Thus, the following research hypothesis can be discussed: highly effective spectrum sharing in small cell networks, relying on the available information on the surrounding environment and presence of other licensed users and on the high flexibility in transmit signal parameter selection, can be a good approach for solving the problem of rapid increase of telecommunication traffic in next generation networks.

What will be the main goals of the proposed project? First, it has to be noticed that in both cases (i.e. small cells and white spaces) the key problem is the presence of interference and radio resource management. Thus, in order to solve this issue we propose in this project to investigate how the waveform adaptivity and dynamic selection of certain signal parameters can minimize the level of interference observed by other users. Of course, adaptive design of transmit signal entails the need of application of advanced reception algorithms. However, one can claim immediately that even in GSM some transmit parameters have been adapted, so what is the real novelty of this proposal? Indeed, adaptive selection of the transmit power, coding rate, number of bits assigned to one data symbol (known as modulation order) are widely and with great success applied in numerous systems. And in fact this is the real basis for the thesis definition and making the project proposal! The research hypothesis can be stated as follows: further increase of flexibility of the design and selection of various transmit signal parameters can enhance the efficiency of the system and can create real benefits. In the proposed project for the first time in the world the concept of waveform adaptivity (including pulse shape modification and modulation type selection) will be considered in the context of spectrum sharing in small cell networks. Let us look at the exemplary illustration below which shows the transmit signal (in fact its power distribution) on time-frequency plane. It consists of the set of pulses (there are $M \bullet N_{tot}$ pulses) of defined shape and placed on specific locations. The distacne between pulses is fixed and is denoted as F and T. The author of this project proposes to adapt such waveform parameters as pulse width (in time and frequency), pulse shape, distance between pulses or their total number. It may happen that depending on the channel conditions it will be better to select the pulse which is wider in time domain and shorter in frequency domain, or - for example - the cosine shape will be better then the rectangular one. Currently most of these parameters are fixed and cennot be modified.



Thus, during the project lifetime the new pulse shape will be optimized (we refer to the pulse that carried user data), as well as new link adaptation algorithms will be proposed together with the advanced reception methods of such adaptively constructed signal. It is however important to verify the theoretical analysis of some basic research problems by means of some hardware experiments. Thus, the test transmission in the white spaces will be conducted in the laboratory. During this experiment various parameters will be measured simultaneously in order to check how the unlicensed signal influences licensed transmissions. I believe that the results achieved in such a way will be in the area of interest of network operators, manufacturers, standardization bodies and regulators. But, if someone would like to ask such simple and colloquial question: what will be real benefit for typical end-user? I would risk a bit and say the following: cheaper and more ecological (due to lower transmit power required for transmission in low frequency band and over short distances), faster (due to application of new wireless systems) and reliable (due to almost unchangeable transmission environment inside the building) Internet access. The confirmation of the research hypothesis will for sure deliver new tools for effective design of future wireless telecommunication systems.