Trends in Wireless Communications Towards 5G Networks – The Influence of E-health and IoT Applications

Invited Paper

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Abstract—**It is expected that the fifth generation (5G) of mobile networks will be standardized in 2020. For this new generation, there are several new performance requirements in addition to higher data rates. E-health and the Internet of Things (IoT) are two important applications that define the new requirements. In this paper, we discuss several technological trends in wireless communications towards 5G networks, highlighting the influence of e-health and IoT applications.**

Keywords—wireless communications; 5G networks; technological trends; e-health; internet of things

I. INTRODUCTION

The first generation (1G) of mobile communication networks offered only analog voice communications. The second generation (2G) was the first digital generation and, in addition to voice, offered text messages with data rates that ranged from 9.6 kbps to 19.2 kbps. Subsequently, for each new generation, the primary goal was to provide higher data rates. The third generation (3G) integrated voice and mobile Internet services, offering data rates ranging from 144 kbps to 2 Mbps. Finally, the fourth generation (4G) supported high-capacity multimedia applications with data rates ranging from 100 Mbps to 1 Gbps [1].

Now, it is time for the fifth generation (5G) of mobile communication networks. The standardization process for 5G began in 2014 and is planned to be finished in 2020 [2]. Again, a higher data rate is a driver behind the technical solutions of the mobile network. However, at this time, there are higher expectations. New applications demand new scenarios, where a higher data rate is not the only requirement for the mobile network. Nominally, Internet of Things (IoT) applications and several e-health applications, which are enabled by Tactile Internet concept, demands different requirements other than higher data rates.

The goal of this paper is to summarize several trends in wireless communications towards 5G networks and analyze the influence of e-health and IoT applications in the requirements of the new generation of mobile networks.

To achieve our objective, we will attack the subject in four steps that define the next sections of the paper: first, we summarize several technological trends related to the mobile terminal and several social and economic trends, in such a way to contextualize the scenario for new application possibilities and necessities; then, we present the requirements for 5G networks from the perspective of e-health and IoT applications; subsequently, we analyze the four scenarios considered for 5G networks and their requirements; and finally, we present the technological trends to achieve all requirements and scenarios previously presented and the conclusions of the paper.

II. TECHNOLOGICAL, SOCIAL AND ECONOMIC TRENDS

Four technological trends related to the mobile terminal have offered new capabilities in terms of applications.

The processing capacity of a generic microprocessor has grown exponentially. For example, in 1995, the Pentium Pro processor had a capacity equal to 161 MIPS (million(s) of instructions per second). In 2000, the Pentium IV processor had a capacity equal to 1342 MIPS; currently, the capacity is approximately 10.000 MIPS [3].

The storage capacity of random access memory (RAM) has grown exponentially, and the cost per stored bit has decreased exponentially. For example, the RAM capacity was 256 Mbit in 2000, was 4 Gbit in 2006 and is currently 256 Gbit. Furthermore, the cost for 1 Gbit of storage was US$ 500 in 2000, US$ 32 in 2006 and US$ 0.25 in 2015 [3]. In the same direction, the storage capacity of flash memories is currently doubling every 18 months, resulting in a10-fold increase in the storage capacity every 5 years [4].

The camera resolution used in mobile terminals has grown exponentially. For example, the resolution was 0.11 Mpixel in 2000, 2 Mpixels in 2005 and 41 Mpixels in 2012 [5].

The cell phone screen resolution has grown exponentially. For example, the resolution was 19.2 kpixels in 2002, 153 kpixels in 2007 and 3.6 Mpixels in 2015.

These four technological trends mean that the user can use more powerful applications; store more data, including high-resolution photos, images and videos; take photos and make videos with greater resolutions; and visualize photos, images and videos with greater quality.

These technological evolutions have resulted in several new multimedia application possibilities and in massive use of mobile networks to access the Internet. Furthermore, due to the offered possibilities, together with the greater data rates in mobile networks, a social trend has emerged: a normal user, who was an information consumer, is now also an information generator. This trend can be easily confirmed by perusing the social networks, such as Facebook, Instagram, YouTube, Twitter and others.

As a result of these technological and social trends, the traffic in mobile networks has also grown exponentially. The exponential growth in traffic has been the primary driver that defined the evolution of mobile networks since the second generation. However, as stated before, due to new applications, such as IoT and several e-health applications, the next generation demands new performance requirements besides higher data rates.

Moreover, it is important to highlight one economical trend related to mobile networks. The number of users in mobile networks is close to the saturation point in most countries, even in developing countries. For example, in Brazil, the number of mobile terminals grew only approximately 12% in the last three years (from 254 million in 2012 to 284 million in 2015). This characteristic has resulted in stabilizing the revenue of telecommunications operators.

Thus, from a telecom operator's point of view, it is extremely important that new applications that are capable of generating new business are developed. Several of these new applications are IoT, M2M (machine-to-machine) communications and new applications enabled by the Tactile Internet concept. For example, see several of the forecasts published by Cisco and by BI Intelligence: the number of M2M connections will grow from 0.5 billion in 2014 to 3.2 billion in 2019, which is a CAGR (compound annual growth rate) equal to 45% [6]; the number of wearable connections will grow from 109 million in 2014 to 578 million in 2019, which is a CAGR equal to 40% [6]; the traffic generated by wearables devices will grow from 15 petabytes per month from 2014 to 277 petabytes per month in 2019 [6]; the number of IoT installed devices will grow from approximately 3 billion in 2014 to approximately 23 billion in 2019, which is a CAGR equal to 57% [7]; and the IoT market will be worth approximately US$ 24 billion in 2019 (approximately 70% of the total market) [7].

III. IoT AND E-HEALTH APPLICATIONS DRIVING THE REQUIREMENTS OF 5G NETWORKS

There are several definitions of the Internet of Things; our preferred definition is from the IERC (IoT European Research Cluster) project [8]: "Internet of Things is a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual things have identities, physical attributes, and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network". In other words, the Internet of Things is an extremely complex, dynamic and flexible network infrastructure that can connect anything, anyone, anytime, in any place, for any service.

IoT has applications in several areas, such as consumer electronics, automotive transport, retail banking, environmental, infrastructures, utilities, health and well-being, smart cities, process industries, and agriculture.

IoT and M2M are expected to be two extremely important drivers to 5G networks. One challenge with these applications is the massive number of terminals, which leads to the necessity of extremely high-dense networks (for example, the forecast of 5GPPP is approximately 7 trillions of IoT devices). Thus, two important requirements to support M2M and IoT applications are scalability and a high connection density (approximately 10^6 connections per km^2 [9]).

Another important point related to IoT is that a number of applications are based on wireless sensor networks, where energy is, in general, the most important performance issue. Thus, an extremely low device energy consumption is another requirement for 5G networks in this scenario (at least 10 years on battery is necessary for certain applications [10]).

One extremely important application to be considered for the next generation of wireless networks is e-health. To understand the economic importance of the e-health sector, see the data published in [11]: "The current average spending in the healthcare sector in Europe is about 10% of GDP (Gross Domestic Product) and the rise in healthcare costs as a percentage of GDP continues to outperform the average economic growth". In the same publication, it is appointed that "mobile health could save 99 billion Euros in healthcare costs in the European Union by 2017 if its adoption is encouraged".

In particular in the e-health area, IoT can enable or improve several applications, for example assets and interventions management in hospitals, remote monitoring, assisted living, behavioral change, treatment compliance, telemedicine and smarter medication [11]. These applications will result in an extremely important business in the near future; for example, according to Forbes magazine, the use of IoT in healthcare will be a US$ 117 billion market by 2020 [12].

Several works have proposed applications that integrate e-health, web services and/or mobile communications, such as the following examples: in [13], a mobile health platform for pressure ulcer monitoring with electronic health record integration is proposed; in [14], a mobile health system for dietetic monitoring and assessment is proposed; and in [15], a novel cooperation strategy for mobile health applications is proposed. In particular, several applications have been proposed to integrate IoT with e-health applications: in [16], the integration of wearable solutions in ambient assisted living environments with mobility support is proposed; in [17], an IoT-based mobile gateway for intelligent personal assistants in mobile health environments is proposed; in [18], a case study of a platform for e-health considering IoT for medical applications is presented; and in [19], an integration of wearable devices in a wireless sensor network for an e-health application is proposed.

As we have seen, IoT can lead to several new applications related to e-health. However, the next wave of innovation in Internet technologies, called Tactile Internet, can enable unimaginable applications.

The term Tactile Internet was coined by Prof. Gerhard Fettweis in [4] and can be defined as an ultra-responsive, ultra-reliable network able to deliver physical haptic experiences remotely [20].

Tactile Internet has applications in several fields, for example, industry, robotics and telepresence, virtual reality, augmented reality, healthcare, road traffic, serious gaming, education and culture and smart grids [21].

The applications of Tactile Internet in e-health are enormous, which would enable sophisticated medical services to be offered anywhere, anytime, for anyone. Several examples include medical expertise using advanced tele-diagnostic tools, enabling remote physical examination (even by touch) through a robot that is remotely controlled, which can offer audio-visual and haptic feedback; sophisticated tele-surgical interventions, offering extremely specialized surgery services for anyone anywhere; tele-rehabilitation applications via an exoskeleton remotely controlled by a therapist with haptic feedback [21]. Another example is offering the capability to walk for people with disabilities using an exoskeleton. In this case, the exoskeleton would need to be controlled by wireless systems to recognize the environment and the presence of other people (with or without an exoskeleton) [4].

The use of Tactile Internet in the next generation of wireless networks brings several extremely important requirements. As defined above, a Tactile Internet must be ultra-responsive and ultra-reliable. For example, for some applications, a 1-millisecond end-to-end latency is necessary. To achieve this end-to-end latency, the one-way delay in the radio interface must be less than or equal to 100 µs. In terms of reliability, a seven nines system, i.e., an outage probability of 10^{-7} might be necessary [4][20][21]. These requirements are incompatible with the current wireless mobile network (4G). For example, the end-to-end latency in this network is approximately 20 *ms* [20][21].

Figure 1 illustrates the Tactile Internet system with their latency requirements. The system consists of a master domain in which an operator with tactile human-system interface remotely controls an actuator (e.g., a slave robot) located in a slave domain [20][21].

In conclusion, the new applications discussed in this section result in new requirements, besides higher data rates, for the next generation of mobile networks, nominally, ultra-low latency, ultra-high reliability, extremely low device energy consumption, extremely high dense networks, extremely high connection density and scalability.

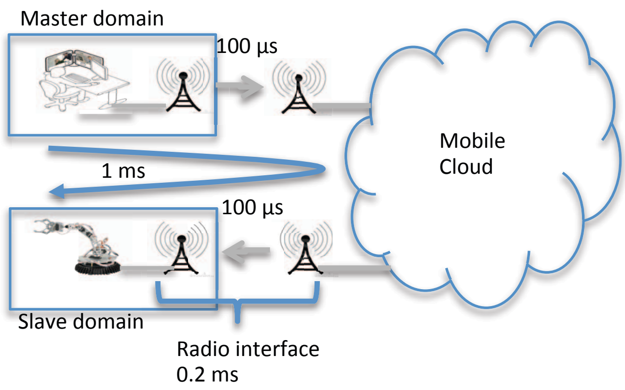

Fig. 1. Tactile Internet System

Furthermore, it is extremely important to keep in mind that in contemporary society, it is no longer acceptable to discriminate people from information and communication technologies and services. Thus, the totality of the aforementioned applications must be offered for all people anywhere. Thus, the next generation of mobile networks must be able to offer these applications and services in extremely high-density urban areas and in rural areas too. This is another challenge when defining the technologies and solutions for 5G networks.

IV. Scenarios for 5G Networks and its Requirements

Based on the discussions above, we can identify four different scenarios for 5G networks: enhanced mobile broadband (bitpipe communications), massive machine type communications, low-latency and high-reliability communications, and WRAN (wireless regional area networks). Each scenario has different applications and requirements, as presented below.

A. *Enhanced Mobile Broadband (EMB)*

In this scenario, the most important requirements are higher data rates and higher traffic capacities. For example, in [9], the following requirements were specified: a user-experienced data rate equal to 100 Mbps in urban and sub-urban areas and equal to 1 Gbps in hotspots; a peak data rate equal to 20 Gbps; an area traffic capacity equal to 10 Mbps/m^2. Thus, the primary objective for this scenario is to improve the data rate and traffic capacity in the network.

In general, this scenario is associated with densely populated urban areas; indoor environments (e.g., shopping centers and office buildings); and crowds at events (e.g., sporting events and festivals). Thus, for this scenario, small cells are expected to be used, e.g., 200 meters (diameter) or less.

B. *Massive Machine Type Communications (MMTC)*

This scenario is related to sensor networks, IoT, M2M communications and several non-critical V2V (vehicle to vehicle) communications.

The primary requirements associated with this scenario are connection density and energy efficiency. For example, in [9], a connection density equal to 10^6 devices/m^2 is specified, and it is affirmed that the energy efficiency must be 100 times better than the energy efficiency in 4G networks. In [10], it is specified that certain devices require a 10-year battery life.

C. Low-Latency and High-Reliability Communications

This is the scenario related with Tactile Internet applications and other ultra-reliable communications, such as V2V communications for self-driving cars.

In this scenario, the primary requirements are low latency and high reliability. For example, an end-to-end latency equal to 1 milliseconds and an outage probability equal to 10^{-7} are specified in [4][11][20][21].

D. Wireless Regional Area Networks (WRAN)

WRAN is the last scenario considered for 5G networks. This is the scenario that will provide new applications to remote areas that are sparsely populated.

In this scenario, the primary requirement is long-range communication with cells greater than 50 km in diameter.

V. Technological Trends for 5G Networks

Based on the scenarios and applications presented in the previous sections, we can summarize the following requirements, several of which conflict, for the next-generation mobile networks: extremely high data rates and traffic capacities; ultra-high connection density; extremely high energy efficiency; ultra-low latency; ultra-high reliability; and long-range communication.

To achieve the requirements presented above, several technological trends for 5G networks can be identified. The remainder of this section is dedicated to summarizing the main and more important trends and how they can be used to achieve the requirements.

A. Massive MIMO (Multiple-input Multiple-output) and 3D MIMO

The Shannon`s Capacity theorem gives an upper bound to the capacity of a link in bit per second and can be used to gain insights on how to obtain higher data rates.

For a system operating with MIMO, the capacity ot he channel can be approximated by (1):

$$C = \min(M,N) \cdot B \cdot \log_2\left(1+SNR\right) \quad (1)$$

where M and N are the number of antennas in the transmitter and the receiver of the MIMO system, respectively, B is the bandwidth of the channel and SNR is the signal-to-noise ratio in the link.

Based on (1), we can see that the data rate can be improved by increasing the number of antennas in the MIMO system. This leads to the first trend for 5G networks: the use of massive MIMO system.

In a massive MIMO system, an extremely large array of antennas is used in the base station (for example, hundreds of antennas) to simultaneously serve several (10s) terminals in the same time-frequency resource [22]. Furthermore, using active antennas in the array, it is possible to control the antenna beam in both the vertical and horizontal directions (this is defined as 3D MIMO), which increases the cell sectorization [23][24]. Furthermore, by controlling the antenna beam, it is possible to improve the SNR, which can improve the capacity of the link or reduce the power transmission, which would save energy. Figure 2 illustrates the idea of massive MIMO and 3D MIMO [23].

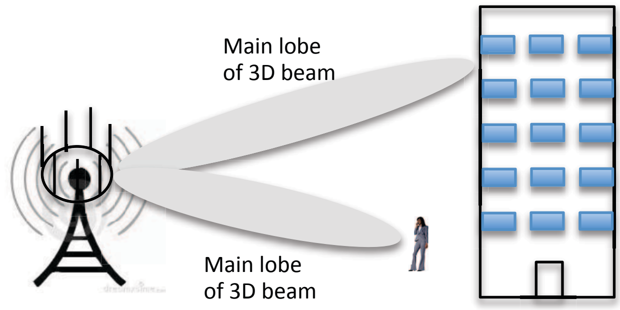

Fig. 2. Massive MIMO and 3D MIMO

According to [22], the use of a massive MIMO can increase the capacity 10 times and simultaneously improve the radiated energy efficiency by approximately 100 times. Furthermore, according to [22], massive MIMO reduces the effects of fading dips, which contribute to reduce the latency in the radio interface.

The massive MIMO trend is particularly connected with the next trend, millimeter wave communications, because at higher frequencies, the antenna array can be miniaturized.

B. Millimeter Wave Communications

Again, from inspecting (1), we can observe that increasing the bandwidth of the channel can increase the data rate. However, to increase the bandwidth of the channel, it is necessary to increase the operation frequency. This leads to the second trend for 5G networks: use of higher frequencies in the millimeter wave band (for example, 57-66, 71-76 and 81-86 GHz).

Using millimeter wave communications can significantly improve the data rate because it is possible at this frequency band to improve significantly the bandwidth of the channel. However, there are several drawbacks in using millimeter wave communications, primarily higher signal attenuation due to free space propagation, atmospheric gases and rain and extremely high absorptions in the material used for buildings [1].

Rain attenuation can be a serious problem in this band, particularly in tropical countries. For example, under a heavy rain (25 mm/h), the rain attenuation at 60 GHz is approximately 10 dB/km. Under a tropical storm (150 mm/h), the rain attenuation at the same frequency is approximately 50 dB/km [1].

To overcome these aforementioned problems several solutions are possible: work with extremely small cells, which would decrease the attenuation; use more directive antennas to compensate for the higher attenuations; or use indoor base stations to overcome the material absorption problem.

C. *Extremely Small Cells, Ultra-dense Networks and Heterogeneous Networks*

Using extremely small cells, besides overcoming the attenuation problem, improves the traffic capacity of the system due to a higher frequency reutilization. Thus, using extremely small cells, which is the basis of the ultra-dense network concept, is another trend for 5G networks.

Furthermore, the use of small cells can increase the SNR if the transmission power is kept constant, which would increase the capacity of the link, or reduce the transmission power, which would increase the energy saving [25].

The use of heterogeneous networks with macro-, pico-, and fento-cells used concurrently is another trend for 5G networks. Several references have defined that a key concept to use small cells is the separation of the control plane and data plane. In this case, the control plane is based on a macro-cell and provides connectivity and mobility, and the data plane is based on pico- and fento-cells and provides data transport [25][26][27][28][29][30]. Figure 3 illustrates this concept.

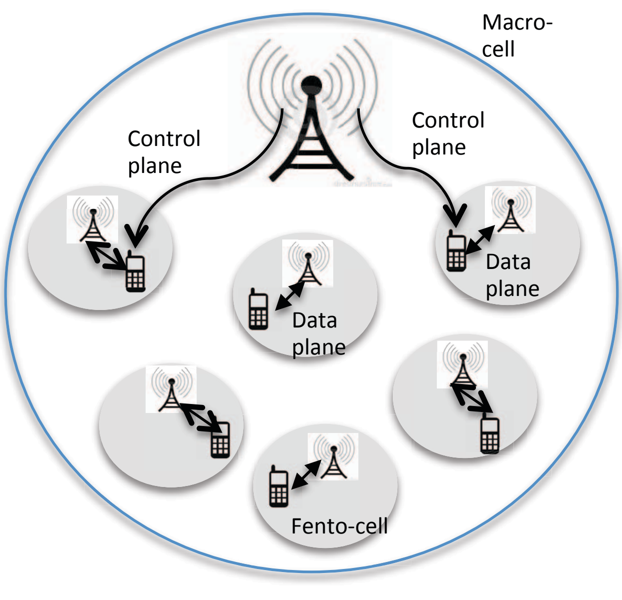

Fig. 3. Heterogeneous network

However, it is important to highlight that using small cells is not appropriated in the WRAN scenario. In this scenario, a super-macro cell likely needs to be considered. Thus, in this scenario, millimeter wave communications cannot be used, and a mixed solution, using millimeter wave communications and lower frequencies, will likely be used in 5G networks.

D. *New Non-orthogonal Waveforms*

The current generation of mobile networks uses OFDM (orthogonal frequency division multiplexing) modulation. However, OFDM cannot achieve the requirements of 5G networks due to several problems [31]:

- High overhead due to CP (cyclic prefix): the inefficient use of CP in OFDM results in high overhead, which reduces the spectrum efficiency and increases power consumption, which limits the use of OFDM in the bitpipe, IoT, WRAN and Tactile Internet scenarios.
- High out-of-band (OOB) emission: carrier aggregation is a key technology to increase the data rate and traffic capacity of 5G networks. Additionally, opportunistic access to the spectrum using the cognitive radio concept is another key technology to increase the data rate and traffic capacity to support WRAN in less populated areas using unlicensed frequencies. To consider these technologies, it is extremely important to have low OOB emission. Thus, the high OOB emission of OFDM limits the implementation of these technologies. The high OOB emission limits the use of OFDM in bitpipe, IoT and WRAN scenarios.
- Synchronization: synchronization is a key factor to obtain good performance in an OFDM system. However, synchronization is a time- and energy-consuming process. In certain applications, such as those defined for the IoT scenario, it is important to consider some waveform that can properly work coarsely synchronized. Thus, the synchronization requirement of OFDM is a limitation of this technique in the IoT scenario.
- Long symbols and long time frame: OFDM uses long symbols and a long time frame, which increases the latency of the radio link. High latency is a significant problem, as discussed above, for the Tactile Internet scenario. Thus, the use of OFDM is a limitation for the Tactile Internet scenario.

Due to the limitations described above, OFDM is not considered for 5G networks. To overcome these limitations, non-orthogonal waveforms have been proposed, which are more flexible and more efficient. The following are several proposed waveforms: GFDM (generalized frequency division multiplexing), UFMC (universal filtered multi-carrier), FBMC (filterbank based multi-carrier), and F-OFDM (filtered OFDM).

E. *Device-to-device (D2D) Communications*

Device-to-device communication has been noted by numerous studies as another trend for 5G networks [25][26][32][33][34].

Device-to-device communications can be used in two different ways. First, one terminal cooperates with another terminal in such way to improve the quality of the communication between the terminal and the base station; this approach is denominated cooperative communications. In the second way, one terminal can establish communications directly with another terminal without the participation of the base station. Both approaches are illustrated in Figure 4.

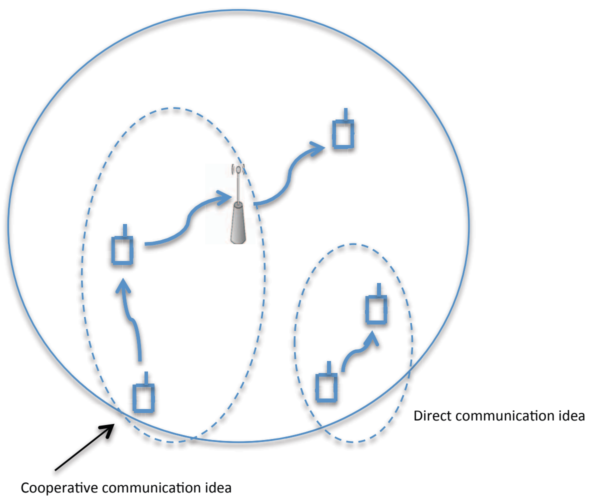

Fig. 4. D2D approaches

The use of D2D for direct communication permits that multiple D2D links simultaneously share the same bandwidth, thus increasing the traffic capacity of the cell. Additionally, the direct communication approach can increase the SNR (when compared with the communication via a base station), which increases the capacity of the link, or can save energy by decreasing the power transmission. Finally, D2D direct communication reduces the latency of the radio link.

The use of D2D for cooperative communication can result in several benefits: improved channel reliability, improved system throughput, seamless service provision, operation cost reduction and improved energy efficiency [35].

F. *Non-orthogonal Multiple Access*

Hitherto, all generations of mobile networks use a type of orthogonal multiple access technique, such as FDMA (frequency division multiple access), TDMA (time division multiple access), CDMA (code division multiple access) and OFDMA (orthogonal frequency division multiple access). In these techniques, different users are allocated to orthogonal resources in frequency, time or code domain.

For the next generation of mobile networks, as discussed above, it is necessary to improve the spectral efficiency and to support massive connectivity in the same cell. In this scenario, orthogonal multiple access is not a good option, and non-orthogonal multiple access (NOMA) has been considered [36].

The use of NOMA has the following advantages: improved spectral efficiency, massive connectivity, low transmission latency and signaling cost [36].

Several non-orthogonal techniques considered for 5G are the following: SCMA (sparse code multiple access), PDMA (pattern division multiple access), MUSA (multi-user shared access), IDMA (interleaved division multiple access), RSMA (receiver sense multiple access), BDMA (beam division multiple access), MUST (multi-user superposition transmission), BDM (bit division multiplexing), and SoDeMA (software defined multiple access) [36].

G. *Cognitive Radio*

Cognitive radio is another important technology to be considered for 5G networks [37]. This technology can be a key technology to enable the WRAN scenario.

In cognitive radio networks the users are classified in primary user and secondary user. The network can operate in two modes: spectrum overlay and spectrum underlay. In overlay mode secondary users can transmit simultaneously with primary users. However, the transmission power of secondary users is limited such that the interference in primary users is kept below a given threshold. In underlay mode secondary users can opportunistically use white spaces in the spectrum allocated to a primary network using dynamic spectrum access. Figure 5 illustrates the operation in underlay mode, more appropriated for WRAN scenario [38].

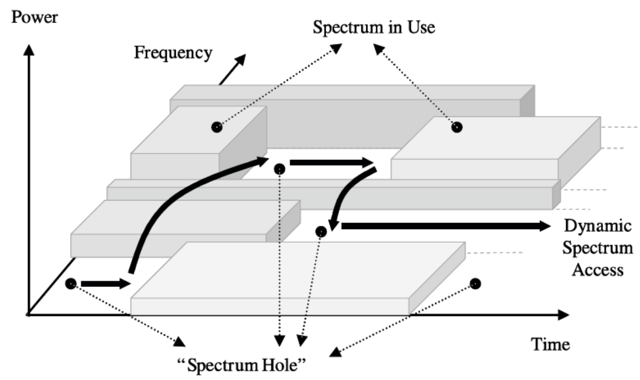

Fig. 5. Dynamic spectrum access in underlay cognitive radio network [38]

VI. Conclusions

The next generation of mobile networks (5G) is at the beginning of the standardization process. For this generation, new requirements besides higher data rate are necessary. Several applications, such as IoT and e-health, have an important role in the definition of the requirements and consequently, in the definition of technologies to be used in the 5G network. In this paper, we presented several technological trends for 5G networks, highlighting the influence of IoT and e-health on these trends.

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