Next Generation 5G Radio Communication NW

Ulrich L. Rohde
BTU Cottbus, Munich, Germany

Ajay K. Poddar
Synergy Microwave NJ, USA

Ignaz Eisele
EMFT, Munich, Germany

Enrico Rubiola
FEMTO-ST Institute, France

***Abstract*—This paper discusses the expectations, challenges, and uncertainties of the next generation 5G radio communication networks. The acknowledged high expectations for new radios place challenges on designers and uncertainties on the selection of the frequency spectrum. Although, research community and industry leaders are engaged towards figuring out the dynamics of 5G (fifth generation), expectation continue high for the next-generation radio standard, which will require higher data rates, massive device connectivity, more system capacity, reduced latency, energy savings, and inexpensive solution. The transition from 4G to 5G can lead to significant augmentation in data rates and latency. Designers are engaged in cope with the needed dimension of time t in 5G, which aims at air latency of < 1 millisecond and cell throughput of > 10 Gbps at millimeter wave frequencies. Therefore, considerable design challenges stretch out ahead for system engineers to integrate novel technologies (CR, SDN, SDR), into interoperable platforms that intelligently connect to local and global NW and offers affordable solutions.**

***Keywords*— 5G, CR, MIMO, Radio, SDN, SDR**

I. INTRODUCTION

The wireless NW (networks) have evolved from 1G to 4G networks, i.e., Frequency Division Multiple Access (FDMA) for 1G, Time Division Multiple Access (TDMA) for 2G, Code Division Multiple Access (CDMA) for 3G and Orthogonal Frequency Division Multiple Access (OFDMA) for 4G, allowing portable smart devices to become important electronic tools in daily life [1]. To meet the rising demand from user, industry and research communities spin out generations of new technology on roughly10-year basis (1G - 1981, 2G - 1992, 3G - 2001, and 4G - 2009). This decade-by-decade introduction of new generation technology has led to the general insight for fifth generation (5G) mobile to emerge around 2019-2020. Nevertheless, the subject matter is what 5G brings to users and at what cost and compromise? The critical parameters for next generation 5G technologies to beat the capability of prior generations: capacity and coverage, latency and reliability, energy consumption and cost, and improved access technology/infrastructure [1]-[4].

The 5G spectrum requirements are primarily driven by the expected increase in traffic capacity demands and the support for increasing users, however in author's view IoT (internet of things) and big data are leading driving force. Although, research community and industry leaders are engaged towards figuring out the dynamics of 5G (fifth generation), expectation continue high for the next-generation radio standard, which will require higher data rates, massive device connectivity, more system capacity, reduced latency, energy savings, and inexpensive solution. The transition from 4G to 5G can lead to significant augmentation in data rates and latency. Designers are engaged in cope with the needed dimension of time t in 5G, which aims at air latency of < 1ms (millisecond) and cell throughput of > 10 Gbps at millimeter wave frequencies. Therefore, considerable design challenges stretch out ahead for system engineers to integrate novel technologies: SDR (software defined radio), SDN (software defined network), and CR (cognitive radio) into interoperable platforms that intelligently connect to local and global NWs at reduced cost.

Table 1 describes the critical deviation between 4G and 5G. The challenge designer faces what changes are requisite to position next generation 5G radios. The possible change is envisaged in combination with 4G LTE, the anchor could be 4G LTE technology with 5G sub-6 GHz as an appendage. Uplink MIMO for 4G requires multiple separate data streams driving discrete antenna elements, identical to sub-6 GHz 5G. These antennas are adjusted for relative phase to beam-form as looked-for, but the lower frequency and lower number of antenna elements constrains the overall antenna gain and the narrowest beam cross-section. Figure (1) shows the typical 5G network, which can enable dual-connectivity between LTE operating within bands below 6GHz and the NX air interface in bands within the range 6 GHz to100 GHz.

Table 1: shows the critical deviation between 4G and 5G

Specifications	**4G**	**5G**
Full Form	Fourth Generation	Fifth Generation
Data Bandwidth	2Mbps to 1Gbps	1Gbps and higher
Frequency Band	2 to 8 GHz	3 to 300 GHz
Standards	AI access convergence including OFDMA, MC-CDMA, Network-LMPS	CDMA and BDMA
Technologies	Unified IP, seamless integration of broadband LAN/WAN/PAN/WLAN	Unified IP, seamless integration of broadband LAN/WAN/PAN/WLAN and advanced technologies based on OFDM modulation
Service	Dynamic information access, wearable devices, HD streaming, global roaming	Dynamic information access, wearable devices, HD streaming, any demand of users
Multiple Access	CDMA	CDMA, BDMA
Core Network	All IP Network	Flatter IP Network, 5G network interfacing
Handoff	Horizontal and vertical	Horizontal and vertical
Initiation from	Year 2010	Year 2015

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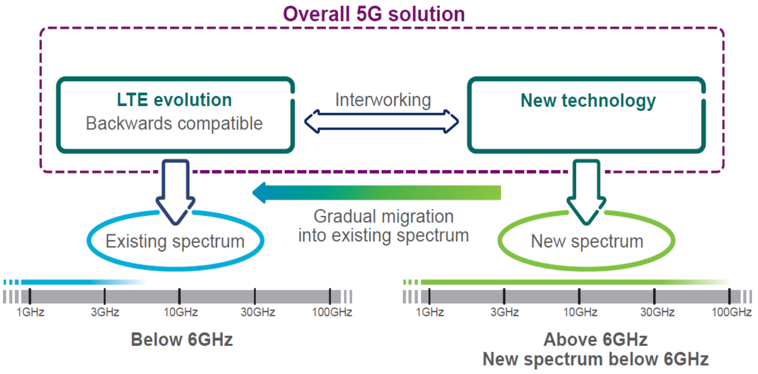

Fig.1: A typical 5G radio consisting of LTE inspired new technology

II. Millimeter Wave: Path to Next Generation

Historically, cellular networks have avoided millimeter ware frequency spectrum because of high propagation loss consequent in shorter transmission distance, reduced building penetration, and succumb absorption from atmospheric particles and rain drops. But short transmission paths due to high propagation losses allow for spectrum reuse application by limiting the amount of interference between adjacent cells. Furthermore, where longer paths are preferred, the shorter wavelengths of millimeter wave signals make it viable for small antennas to concentrate signals into extremely focused beams with adequate gain to surmount propagation losses. Also, the short wavelengths of millimeter wave signals formulate to construct multi-element, dynamic beamforming antennas that will be in compact size to fit into wireless handsets. For millimeter wave inspired next generation radio communication networks, a requirement is to characterize the propagation/attenuation dynamics at the specific frequencies and the relevant use-cases [3].

Figure (2) shows the typical atmospheric absorptions characteristics. It can be seen from Figure (2), 28 GHz and 38 GHz exhibit low absorption, can be suiatble candidate for 5G cellular systems. At these frequencies, the millimeter wave bands offer a massive amount of unlicensed spectrum. In fact, 28 and 38 GHz frequencies can be used to employ steerable directional antennas at base stations and mobile devices. At millimeter wave with their shorter wavelengths, make the realization of dense antenna arrays for massive MIMO systems practical as compared to lower-frequency systems [4].

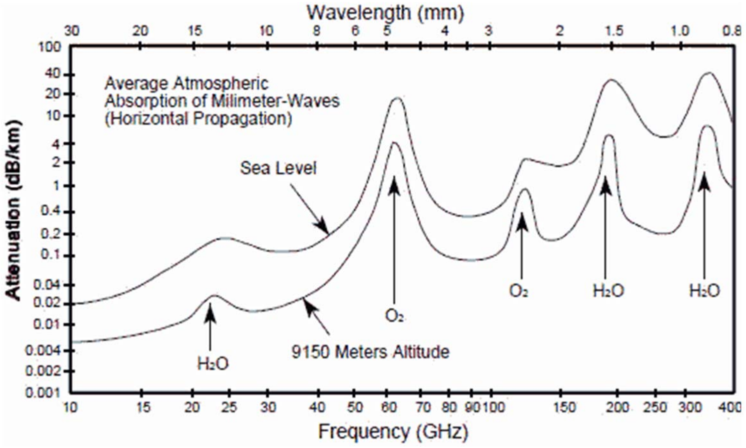

Fig.2: Shows the typical atmospheric absorptions characteristics

As depicted in Figure (2), the frequency window operating at millimeter wave spectrums permit opportunity of frequency spectrum reuse. And, supports advantaged frequency bands for point-to-point system such as local area network and vehicular radar system. Also, in the absorption resonance bands, for example 60 GHz, moderately secure communication network can be established, especially for high data rate systems where secure communications with a low probability of intercept is much sought-after [3]-[4]. These frequency bands are useful for services with a potentially high density of transmitters operating in proximity or for applications where unlicensed operations are desirable.

A. Millimeter Wave: Next Generation (5G) Radio Enbaler

Millimeter-wave is being considered as a key enabler of 5G by allocating more bandwidth to deliver faster, higher-quality video, and multimedia content and services. On the contrary, at lower frequencies, the same array of multiple antennas would render the large physical towers for cellular networks that are awfully impractical. The major confront in urban areas surrounded by tall buildings is desired signal penetrations. To support adequate coverage for users surrounded by tall buildings in big cities, base stations will necessitate being closer to improve capacity as well as should be cheaper to stay sustainable. For example, a typical 5G MIMO base station equipped with many more antennas would be able to serve more devices as envisioned by 5G and IoT applications. Figure (3) shows a comparison of a typical 4G MIMO cell to that of a 5G massive MIMO cell that is in principle equipped with many more base station antennas.

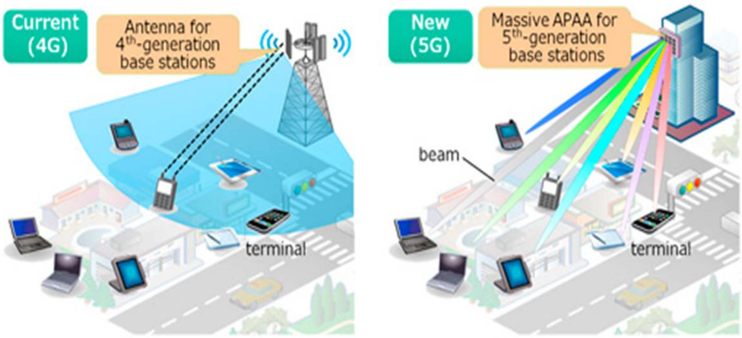

Fig. 3 Shows the typical antenna technology from 4G to 5G MIMO

B. Proposed 5G Millimeter Wave Frequency Standards

The proposed 5G millimeter wave frequency standard demands for following requirements: peak data rate >10Gbps, cell edge data rate of 100Mbps and 1msec latency end-to-end; could potentially be met in a variety of carrier frequencies. It is to note that peak data rate is empirically related to available spectrum as per Shannon-Hartley theorem, which states that capacity is a function of bandwidth and channel noise. For this reason, choice of high frequency in the millimeter wave range becomes necessary for 5G radio standard since it comes with large bandwidth. Recently, 3GPP (3rd Generation Partnership Projects) and ITU (International Telecommunication Union) have proposed two phase plan for 5G standards, Phase-1 (under 40 GHz), and Phase-2 (up to 100 GHz). ITU released a list of frequencies in millimeter wave ranges (between 24 GHz and 86 GHz): 24.25-27.5 GHz, 31.8-33.4 GHz, 37-40.5 GHz, 40.5-42.5 GHz, 45.5-50.2 GHz, 50.4-52.6 GHz, 66-76 GHz, and 81-86 GHz. FCC (Federal Communications Commission) in the USA (United States of America) issued a Notice of Proposed Rule Making (NPRM) that recommended new flexible service rules among the 28 GHz, 37 GHz, 39 GHz, and 64-71 GHz bands for next generation new 5G radios.

The proposed frequency spectrums that are gaining early momentum as a 5G new radio are: 28 GHz, 39 GHz, and 73 GHz. The leading runner is 28 GHz, the close follower is 39 GHz, and the real deal could be 73 GHz. Based on Shannon-Hartley theorem, more bandwidth equates to more data throughput, and that gives 73 GHz a big benefit over the other contenders. One key plus point of 73 GHz that sets it apart from 28 GHz and 39 GHz is the available contiguous bandwidth. For example, with 2 GHz of contiguous bandwidth for mobile communications, 73 GHz is the widest of the proposed frequency spectrum. By comparison, 28 GHz offers 850 MHz of bandwidth and for example in the USA; the two 39 GHz bands offer 1.6 GHz and 1.4 GHz bandwidth.

Down the line, ITU would play an important role in setting one frequency for mobile use with millimeter wave 5G wireless standards. This will provide a great financial support to handset makers and network infrastructure vendors if only one set of silicon instead of the multiple chips needed in 5G for global coverage. The verdict of a single band that can be agreed upon globally should be considered as an integrated task to strive for. Recently, 3GPP considers 3-bands for evaluation: sub-6 GHz (around 2 GHz or around 4 GHz), around 30 GHz, and around 70 GHz. The higher carrier frequencies are foremost linked with higher bandwidths but also exhibit lower channel coherence times, described by [2]

$$T_C = \sqrt{\frac{9}{16\pi v}}\frac{c}{f_c} \qquad (1)$$

Where c is the speed of light in meter/second, v the speed of mobile in meter/second, T_c is the channel coherence time in seconds, and f_C the carrier frequency in hertz. From (1), the channel coherence time depends on the carrier frequency.

C. Millimeter Wave: Reservations and Road Map for 5G

There are reservations about the usage of millimeter wave frequency spectrum for 5G radio networks. Some argue that the desirability of millimeter wave spectrum is over-hyped for next generation radio communications. The fundamental basis for disagreement is millimeter wave signals do not propagate far and also unable to penetrate through numerous objects. This creates requirement of numerous base stations to cover a given region, for which site rental and backhaul expenses will become prohibitively pricey. They strongly believe that the usage of millimeter wave frequency spectrum will be limited to hotspots, in contention that sub-6GHz spectrum is likely to represent the “sweet-spot” for 5G radios. Despite above reservations, the support and momentum for millimeter wave to enable new 5G radios are ever growing strong. At any rate, high frequencies are preferred compared to the traditional lower frequency bands for two reasons: (i) larger bandwidth availability, and (ii) compact smaller antenna dimensions for a fixed gain, or higher gain for a given antenna size. It is well well-known that larger bandwidth is directly proportional to higher data transfer rates. Additionally, a larger bandwidth enables wideband spread-spectrum systems for reduced multipath and clutter, and systems with a soaring immunity to jamming and electromagnetic interferences.

The recent emerging trends in support of millimeter wave inspired spectrum roadmap for 5G lead to choice of several cellular-radio design schemes. One way forward on this roadmap would be to use cognitive-based SDR technology, allows communications via a variety of waveforms simply by reloading or reconfiguring the required software for the particular application. If integrated into 5G networks, cognitive SDR has the potential to help identify available frequencies and spectrums and reconfigure itself for the optimum performance. Stakeholders from all fronts (service providers, chipset and device manufacturers, and network infrastructure vendors) are unified towards defeating the challenges associated with millimeter wave frequency spectrum and move forward for cognitive SDR-SDN to meet data throughput requirement at lower cost [1]-[4].

III. RADIO CLASSIFICATIONS AND EVOLUTIONS

Conventional hardware based radio devices limit cross-functionality and can only be customized through physical intervention. This results in higher manufacture overhead and no flexibility in supporting multiple-waveform standards. The evolution and classification of radio (HR, SCR, SDR, ISR, and USR) is given in terms of capability and complexity.

- **Hardware Radio (HR)**
    - No changes to system can by done by software
- **Software-Controlled Radio (SCR)**
    - Control functionality implemented in software, but change of attributes (modulation and frequency band) cannot be done without changing hardware
- **Software-Defined Radio (SDR)**
    - Capable of covering substantial frequency range and executing software to support variation of modulation techniques, wide-band or narrow-band operation, enable security function, meet waveform performance requirements of legacy systems
    - Capable of storing large number of waveforms or air interfaces, adding new by software download
    - System software should be capable of applying new or replacement modules for added functionality or bug fixes without reloading entire set of software
    - Separate antenna system followed by some wideband filtering, amplification, and down conversion prior to receive A/D-conversion
    - The transmission chain provides reverse function of D/A-conversion, analog up-conversion, filtering and amplification
- **Ideal Software Radio (ISR)**
    - All capabilities of SDR, but eliminates analog amplification and heterodyne mixing prior to A/D-conversion and after D/A conversion
- **Ultimate Software Radio (USR)**
    - Ideal software radio in a chip, requires no external antenna and no restrictions on operating frequency
    - Can perform a wide ranges of adaptive services

The future is going to be USR in millimeter wave spectrum.

In this paper, high performance SDR inspired radio receiver is reported for applications in radio monitoring. The term SDR using DSP of sampled analog signals was coined by author in 1985, which is the first public software radio initiative reported with following characteristics [1]:

- Ease of design
  - Reduces design-cycle time, quicker iterations
- Ease of manufacture
  - Digital hardware reduces costs associated with manufacturing and testing radios
- Multimode operation
  - SR can change modes by loading appropriate software into memory
- Use of advanced signal processing techniques
  - Allows implementation of new receiver structures and signal processing techniques
- Fewer discrete components
  - DSP implement functions synchronization, demodulation, error correction, decryption, etc.
- Flexibility to incorporate additional functionality
  - Can be modified in the field to correct problems and to upgrade

From (1), technologies that enable SDR [1]:

- Antennas
  - Receive antennas are easier to achieve wide-band performance than transmit ones
  - New fractal & plasma antennas expected in smaller size and wideband capability
- Waveforms
  - Management and selection of multiple waveforms
  - Cancellation carriers and pulse shaping techniques
- Analog-to-digital converters
  - High ADC sampling speed
  - ADC bandwidth could be digitized instantaneously
- Digital signal processing/FPGAs
  - More specific purpose DSPs and FPGAs
- Batteries
  - More and more power needed (need to focus on more efficient use of power)
  - Fuel cell development for handhelds
- Terrain databases
  - Interference prediction, environment awareness
- Cognitive science
  - Know how multiple CRs work with each other

A fundamental challenge with SDR is how to achieve sufficient computational capacity, in particular for processing UWB high bit-rate waveforms, within acceptable size, power consumption, cost, and weight factors. SDR offers the flexibility of varying bandwidth and range, the ability to adapt to environmental parameters and employ optimal broadband pulse characteristics for channel equalization and robustness, and finally the capability to easily adapt to current and later generation communication infrastructures. The reported radio monitoring receiver (R&S ESMD) as shown in Figure (4), provides the SDR inspired UWB technology implementation for applications such as detecting unknown signals, identifying interference, spectrum monitoring, spectrum clearance, and signal search over wide frequency ranges, producing signal content and direction finding of identified signals. The dynamic range of active antennas plays an important role and is an interesting parameter for further investigation for ultra wideband (UWB) technology implementation on SDR platforms for next generation communication networks. Figure (5) shows the IEEE draft for "standards drive" development. As illustrated in Figure (5), CR will be the future for communication standard because of flexibility/intelligence lead to real time dynamically accessing the spectrum. Key components of next generation radios will include access-backhaul integration, flexible duplex, flexible spectrum usage, multi-antenna transmission, ultra-lean design, user/control separation, and device-to-device communication.

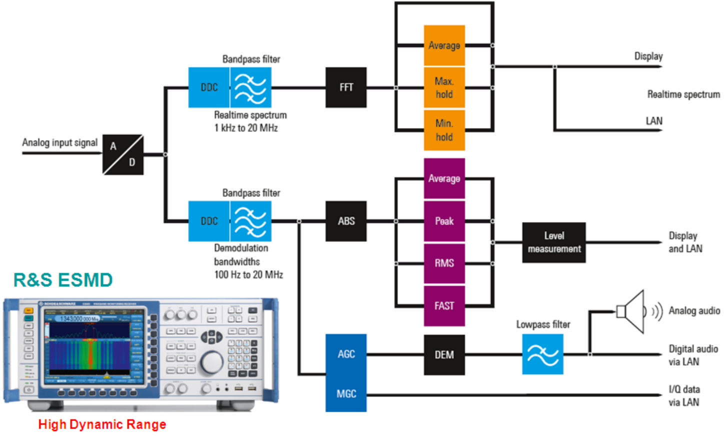

Fig. 4: SDR inspired next generation receiver (courtesy R&S)

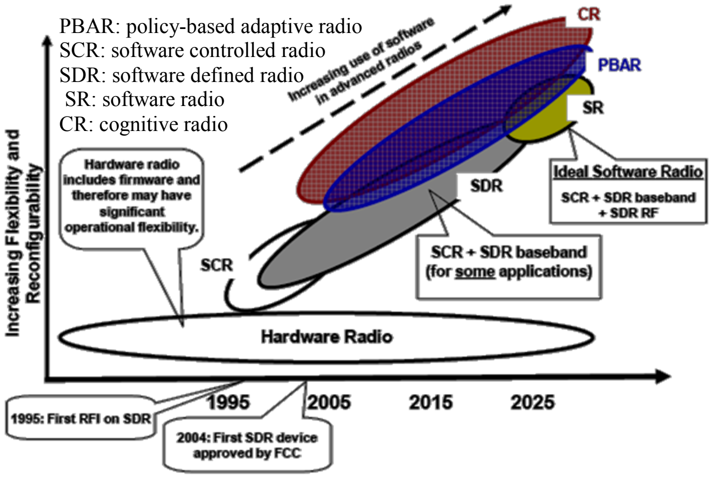

Fig.5: Shows the graph of "standards drive development"

IV. CONCLUSION

Next Generation Radios will be realized by the evolution of LTE for existing spectrum in combination with new radio technologies: SDR, SDN and CR, which target new spectrum.

REFERENCES

[1] Ulrich Rohde, Digital HF Radio: "A Sampling of Techniques, presented at the 3rd International Conf. on HF Communication Systems and Techniques", UK, Feb 26-28, 1985.

[2] Bartelt et al. "5G transport network requirements for the next generation fronthaul interface", EURASIP Journal on Wireless Communications and Networking, 2017

[3] Ulrich Rohde, Jerry Whitaker, "Communications Receivers: Principles and Design", 4th Edition, McGraw-Hill, March 2017

[4] Wei et al., "Software Defined Radio Implementation of a Non-Orthogonal Multiple Access System towards 5G*", IEEE Access, *pp.*: 9604 - 9613, 2016.