Wireless Communications Education: A Guide to Important Topics

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Abstract - **The paper is intended for newcomers as a roadmap to the more important list of concepts of the Wireless Communications area and surveys, with a bird's eye view, the vast area of wireless communication systems and the developments that led to 3G Wireless standards such as UMTS and IMT2000, the latest multi-nationally negotiated 3G standard. Due to the span of the area and the size of this paper, the paper does not go into any depth of a particular subject, but rather organizes the most relevant topics in Wireless Applications, to serve as a guide to delve into more depth, in a logical manner, into the various subjects as could be presented in an undergraduate/graduate course on Wireless Communications systems.**

The topics were selected from a review of a representative selection of recent textbooks and articles, written by workers / researchers in the field of Wireless Communication Technologies, from academia and industry [1-41].

We first present the types of applications and services available over IMT-2000, and the most important Organizations involved in the Wireless Standards Evolution from 1G to 3G Systems. Other topics which are briefly surveyed are the issue of Wireless Capacity and ways to resolve its scarcity, from Access Methods to Network Intelligence, Key Enabling Technologies for the design of 3G /4G systems, Wireless Network Architecture of various sizes from PAN´s (Personal Area Networks) to WAN´s (Wide Area Networks), and the issue of Network Inter-working. Indeed, Inter-working of various Wireless Networks standards and topologies to provide a full set of features such as broadband, adaptable or reconfigurable, all-IP connectivity, to form an Ad-Hoc Wireless Network will be at the heart of the B3G/4G systems.

KeyTerms - **Wireless Communications Education, Wireless Enabling Technologies, 3G Standards, Ad-hoc Reconfigurable Wireless Networks, all-IP Networks.**

I. INTRODUCTION

The paper is organized as follows: *Section 2* gives an overview of Wireless Applications and services for 3G, *Section 3* surveys the evolution of Wireless standards from its 1st generation to the current 3G standards embodied in IMT2000*; Section 4* covers the organizations and standards developed for 3G applications, *Section 5* covers IMT2000 the full 5 part set of third generation standards; *Section 6* covers the issue of Wireless Resource Sharing and the type of Multiple Access used over time; *Section 7* talks about the various Multiple access schemes in more detail, and the technologies that support them. *Section 8* talks about the various Wireless communication Technologies currently deployed in 3G systems. *Section 9* covers Network Operations and what are the envisaged standards capabilities of wireless networks beyond 3G and finally *Section 10* presents the conclusions of the paper.

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II. WIRELESS APPLICATIONS AND SERVICES

Wireless Applications are those which use free space as the transmission medium and do not involve cabling – fiber or copper-. From the type of application, they can involve, depending on the information carried, for example: voice, data, video and multimedia applications and services such as VHF, microwave TV transmission, millimeter wave data transmission, cellular telephony services, Wireless Video-Telephony and Video Conferencing, Wireless PBX, Wireless Broadband Internet and Intranet Access, HDTV, Digital Audio Broadcasting (DAB) or Hi-Fi Sound, Wireless Geo-location Services [1], Wireless Email, PCS Interactive applications using WPANS, WLAN´s, and WMAN networks [2].

A categorization from a user-centered viewpoint of "future desired" services, was proposed in UMTS and labeled as the 5 M's of Service: Movement (to escape a fixed place), Moment (expanding concept of time), "Me"(expanding to a community), Money (Financial resources), and Machine (to empower gadgets and devices) [3], together with the important issue of marketing of these 3G services. [4].

IMT2000 -the 3G harmonized standard for Wireless communications- has proposed the following 6 service classes, listed in Table 1 below [5] and classified as a function of increasing data rate: from Speech to Medium, High & Interactive Multimedia.

TABLE 1.
SERVICE TYPES AVAILABLE OVER IMT-2000

Service	Upstream Data Rate	Downstream Data Rate	Type of Switching Used
Interactive Multimedia (Videoconference)	256 kbps	256 kbps	(Virtual) Circuit
High Multimedia (TV)	20 kbps	2 Mbps	Packet
Medium Multimedia (Web Surfing)	20 kbps	768 kbps	Packet
Switched Data (Fax)	20 kbps	43.2 kbps	(Virtual) Circuit
Simple Messaging (Email)	28.8 kbps	28.8 kbps	Packet
Speech (Telephony)	28.8 kbps	28.8 kbps	(Virtual) Circuit

III. EVOLUTION FROM 1G TO 3G STANDARDS

1G - First Generation or 1G standards were mostly developed in the 1980s. Examples of 1G systems are: Analog AMPS (Advanced Mobile Phone system) from the US, E-TACS (Total Access Communication System) in the UK, NMT 450/900 (Nordic Mobile Telephones) in Scandinavia, C450 in Germany and Portugal, RMTS in Italy, Radiocom2000 in France, NTT (Nippon Telephone and Telegraph) and JTACS/NTACS in Japan [2].

2G – Second Generation systems encompass both PCS (Personal Communication Systems) and Digital Cellular 2G Systems, which differ in aspects such as cell size and power [2]. Some 2G PCS example systems are Cordless Telephone systems such as TDMA/TDD based Europe/Canada's CT-2 and CT-2+, and Europe's DECT (Digital Enhanced/European Cordless Telecommunications/ Telephone). DECT has the highest data rate of 1,728 kbps of all TDMA digital cellular systems (even higher than GSM). There is also US's equivalent PWT (Personal Wireless Telecommunications) and Japan's PHS –which became PHP- also TDMA/TDD based [6] and PACS which was TDMA/FDD based [2].

Among Cellular digital 2G standards, there is GSM, (Europe's Groupe Special Mobile), with TDMA/FDD access method and the 3 standards derived from it: Digital Communications System DCS-1800, Personal Communication Services PCS-1900, and GSM-400. Other well known 2G Digital Cellular standards are IS-54, from the US and JDC from Japan, also TDMA/FDD based as well as the first CDMA/FDD based standard: IS-95.

2.5G - The interim set of Enhanced 2G set of standards which led to 3G standards is formed by General Packet Radio Services (GPRS), a GSM enhancement, and two protocol enhancements to the cdmaOne protocol (originally called IS/95) named IS-95B, and 1XRTT with an extension of GPRS called EDGE (Enhanced Data Rates for GSM Evolution). EDGE is an evolution of GPRS towards 3G standards, compatible with other TDMA systems such as D-AMPS and Japan's Pacific Digital Cellular, PDC, originally embodied in the UMTS WCDMA and CDMA2000 standards and have now been included in IMT2000, discussed below [7, 8].

3G - Third Generation Standards, associated to Wide area networking coverage (WAN)s, are dominated by WCDMA access methods (Wideband CDMA with a 5Mhz channel bandwidth. This is four times the bandwidth of cdmaOne and 25 times that of GSM) and embodied in UMTS and the latest IMT2000 standard, reviewed below. In addition to the 3G WAN standards, there are also WPAN and WLAN standards which ensure full connectivity and multimedia to form the future broadband wireless ad-hoc networks [9].

The dominant transmission technology in broadband WLANs is OFDM, and some predict that UWB will succeed OFDM as the next 4G technology [2]. Another important difference between 3G WAN standards and WLAN/WPAN standards is that the former operate on licensed bands, whereas the latter operate in unlicensed bands such as the Industrial, Scientific, and Medical (ISM) band used by Bluetooth [10]. WLAN standards are, for example, the 802.11 and the HiperLAN family of standards [11]. WMANs are represented by the 802.15 (WiMAX) set of standards, and WPANs are, for example: Bluetooth, WAP, HomeRF and infrared LANs. Interoperability has to address issues such as the interference between Bluetooth and 802.11 networks. Other networks can be based in standards such as Wireless ATM, Wireless Local Loops (WLL), fixed broadband access with LMDS, and satellites [2]. Japan's DoCoMo launched I-mode, the first operational 3G service [12].

B3G/4G–Research is being undertaken for the definition of Beyond 3G (B3G) and 4G characteristics and standards [13].

IV. WIRELESS ORGANIZATIONS & STANDARDS FOR 3G

The various organizations that created the standards for 3G wireless communications are surveyed below.

The development of a Wireless Industry involves different actors among which we can count Standards Bodies (ETSI, ARIB, TIA, ITU), Regulatory Authorities, Supporters of 2G networks (D-AMPS, GSM, PDC and cdmaOne) and Cooperatives of Standards bodies such as 3GPP and 3GPP2 which together formed the Operators Harmonization Group OHG [6].

3GPP[14,15] was formed by Japan's ARIB (Association of Radio Industries and Business) and TTC (Telecommunications Technology Committee), China's Wireless Telecommunications Standards Group or CWTS, Europe's ETSI, United States ANSI's T1 Committee and the Telecommunications Industry Association (TIA), and Korea's Telecommunications Technology Association (TTA).

3GPP2 was formed by US's TIA, Japan's ARIB and TTC, Korea's TTA and China's CWTS. These two groups 3GPP and 3GPP2 have been the driving forces for the evolution towards 3G standards, which we survey briefly below [7].

The 3G standard evolving from D-AMPS was driven by the UWCC or Universal Wireless Communications Consortium, formed by Ericsson, Lucent, Nokia, Nortel, Alcatel, Motorola, Hughes and TDMA operators to create the UWC-136 3G standard [7].

V. IMT2000 – THE FULL SET OF 3G STANDARDS

IMT2000 is an International Mobile Communications standard –previously called FPLMTS for Future Public Land Mobile Telecommunications System- agreed upon in year 2000 which will support Internet, Multimedia and Telephony Services implemented in a cellular network for high speed data with two primary access modes: CDMA and TDMA [16].

IMT2000 embodies 5 parts or standards: four CDMA based standards, and a TDMA based proposal to ensure compatibility with EDGE/UWC-136. Their predecessor standards are shown in parentheses. The four CDMA based standards are IMT-DS (UTRAN FDD), IMT-MC (cdma2000), IMT-TC (UTRAN TDD), IMT-SC (EDGE/UWC-136) and a TDMA/FDMA standard called IMT-FT (DECT), as shown in Figure 2 below [16].

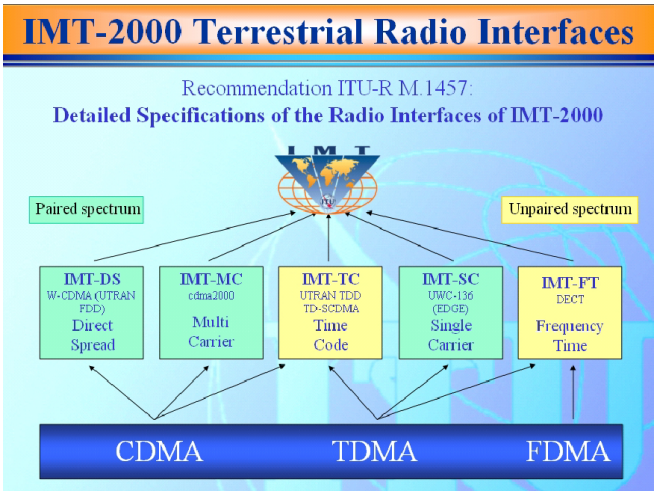

Figure 2. IMT-2000 Terrestrial Radio Interfaces
(*Source*: [16] "What is IMT-2000?" ITU, Geneva 2001-2002).

1. ***IMT-2000 CDMA with Direct Sequence Spread Spectrum (IMT-DS):*** Includes the first operational mode of UMTS, known as UTRA FDD[14], which evolved from GSM. It corresponds to the Direct Sequence WCDMA or FDD WCDMA based on the UTRA standard with FDD duplexing as specified by 3GPP.
2. ***IMT-2000 Multicarrier CDMA (IMT-MC):*** Includes MC-CDMA or the CDMA2000 [17] standard equivalent as per 3GPP2, & constitutes UMTS´s principal competitor. It uses synchronous CDMA, as opposed to the asynchronous CDMA modes of UMTS.
3. ***IMT-2000 CDMA TDD (IMT-TC):*** Includes UMTS Terrestrial mode of access (UTRA) TDD [15] mode equivalent or TDD WCDMA standard, and the Chinese TD-SCDMA (Time Division Synchronous CDMA) where Time Division Duplexing is used to share a channel between uplink and downlink, with the multiplexing access technique still being CDMA (though it is sometimes referred to as TDMA/CDMA).
4. ***IMT-2000 Single Carrier TDMA (IMT-SC):*** Compatible (TDMA-based) UWC-136/EDGE (2.5G)
5. ***IMT-2000 FDMA /TDMA (IMT-FT):*** Includes de 2G DECT standard for backward compatibility.

The TDD and FDD WCDMA standards were supported by ETSI and Japan's ARIB, TD-SCDMA was supported by CWTS, and MC-CDMA or CDMA2000 was supported by CDG or the CDMA Development Group of Industrial Partners whose most prominent member is Qualcomm. Qualcomm's CEO Andrew Viterbi is the inventor of CDMA technology [18]. There are now various competing CDMA systems of which only cdma2000 3XMC proposed by Qualcomm with a 3.75Mhz bandwidth has been approved by ITU to be part of IMT2000. The remaining CDMA upgrade standards to cdmaOne, Qualcomm's CDMA 1XMC, and cdma2000 HDR and Motorola/Nokia's cdma2000 1Xtreme, have a channel bandwidth of 1.25Mhz in contrast to the 5Mhz bandwidth of the WCDMA standard proposed by UMTS. The maximum capacity of the 1Xtreme standard is claimed to be 5.2Mbps in contrast to the 4Mbps of both cdma2000 3XMC and UMTS's WCDMA [5]. The 5 IMT2000 standards: IMT-DS, IMT-MC, IMT-TC, IMT-SC and IMT-FT, (see Figure 2).

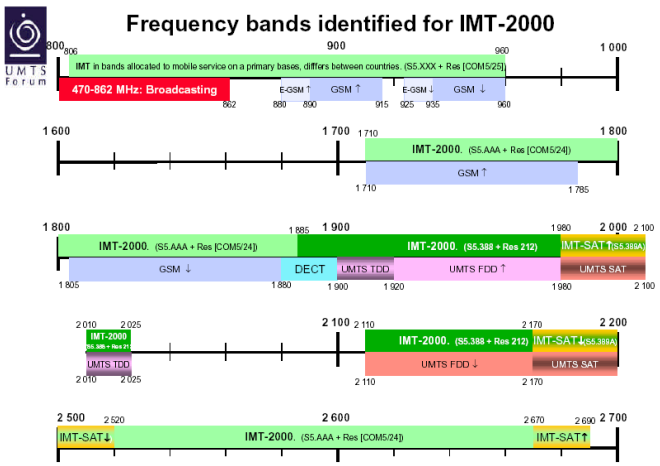

Figure 3. Frequency Bands Allocated to IMT-2000
(*Source*: [19])

The 5 IMT2000 standards are divided into 12 paired bands (6 for the FDD uplink and 6 for the FDD downlink operation) and 7 bands of unpaired spectrum, for TDD operation [6]. The frequency assignment for 3G networks extends between 1850Mhz and 2200Mhz, and 160Mhz of new extension bands are already being sought for service before 2010, to support the expected growth of 3G services in Europe (EMEA) America, and Asia (see Table 2 below).

TABLE 2
SUGGESTED SPECTRUM EXTENSION BANDS FOR 3G

Frequency Band	Application in 2004
420-806 Mhz	UHF band for Analog TV Broadcasting
1429-1501 Mhz	Cordless Phones, Fixed Wireless, Broadcasting
1710-1885 Mhz	In Europe/Asia for air traffic control. Free in America.
2290-2300 Mhz	Fixed Wireless and Deep Space Research
2300-2400 Mhz	Fixed Wireless and Telemetry. Preferred by many operators and regulators.
2520-2670 Mhz	Broadcasting, Fixed Wireless, satellites. UMTS forum Preferred Extension band.
2700-3400 Mhz	Radar and Satellite Communications.

TABLE 3
COMPARISON OF IMT-2000 FDD AND TDD [20]

	FDD - Component	TDD - Component	
Multiplex technology	W-CDMA	TD-CDMA	TD-SCDMA
Bandwidth	2*5 MHz paired	1*5 MHz unpaired	1*1,6 MHz unpaired
Frequency Re-use	1	1	1 (or 3)
Handover	soft, softer (Interfreq.: hard)	hard	hard
Modulation	QPSK	QPSK	QPSK and 8-PSK
Receiver	Rake	Joint Detection Rake (Mobile Station)	Joint Detection Rake (Mobile Station)
Chip Rate	3.84 Mcps	3.84 Mcps	1.28 Mcps
Spreading Factor	4 – 256	1, 2, 4, 8, 16	1, 2, 4, 8, 16
Power Control*)	fast: every 667 µs[1)]	slow: 100 cycles/s[2)]	slow: 200 cycles/s[2)]
Frame organisation	0.667 / 10 ms	0.667 / 10 ms	0.675 / 5 ms
Timeslots/Frame	N.a.	15	7

*) Range: 80 dB (UL); 30 dB (DL) in steps of..... [1)] 0.25 to 1.5 dB [2)] 1, 2 or 3 dB

(*Source*: [20] C. MENZEL,
"*IMT-2000 Members UTRA-TDD and UTRA-FDD*",
www.itu.int/ITU-D/tech/imt-2000/ warsaw/pdf/2_1_Menzel.pdf)

VI. THE ISSUE OF WIRELESS RESOURCE SHARING

The variety of current 3G applications, and future envisaged services points of course to a scarcity of one of the two main wireless resources: a) Transmitter power which affects the sizing of batteries, receivers, antennas and health issues), and b) spectrum (the other important one being power). The needed optimization of the Wireless resources means that we have to share them, and various sharing mechanisms have been used over time for wireless communications.

The principal ways of sharing spectrum have entailed using different user access modes which essentially multiplex the users onto one of the resources: frequency, time, codes and space. More recently, another way of optimizing the wireless resources has been to add intelligence and reconfigurability to the wireless network thanks to the added processing power that has come from higher integration.

The added intelligence has produced both novel signal transmission techniques and advanced receiver signal processing methods with so called 4G technologies [21] such as smart antennas, adaptive coding, reconfigurable Modulation, Space-Time Coding, Channel Equalization, Multi-user detection (MUD), Rake Receiver Combining and Coded Orthogonal Frequency Division Multiplexing (COFDM) [22, 23].

6.1 Multiple Access Techniques [24]

The 1G of Wireless services (AMPS) used FDMA or Frequency Division Multiple Access, the 2G (GSM, GPRS, EDGE) used TDMA-Time Division Multiple Access, and most of the 3G standards, except for EDGE/UWC-136 use CDMA or Code Division Multiple Access (cdmaOne, cdma2000 standards). In addition to the above, there is a Spatial Division Multiple Access method (SDMA) [24] which takes advantage of spatial diversity of antennas, which is being now considered for B3G and 4G wireless networks, such as MIMO Ad-hoc Networks [9].

6.2 Multiple Access and Technology Evolution

6.2.1. Modulation and FDMA

It is interesting to note that there also has been a parallel development of Multiple Access Techniques and Wireless Communication Technologies over time: FDMA allows each user to use a sub-band of the frequency spectrum all the time, and was used when the greater part of the communications design involved modulation techniques. FDMA is the main access technique in radio and TV broadcasts, and was used in analog cellular networks such as AMPS and NMT in the 1970s/1980s [23].

6.2.2. Coding and TDMA

After Shannon's 1948 redefinition of a communications system and the introduction of the concept of information and the use of coding to approach a theoretical system capacity, TDMA was primarily used in conjunction with new coding techniques. TDMA allows a user to occupy the full spectrum during part of the time, and the frequency resource is shared in time amongst users. TDMA is notably used in GSM and its upgrade standards, and in the IEEE 802.16 Wireless MAN standard.

6.2.3. Spread Spectrum and CDMA

The concept of spread spectrum modulation paralleled the use of CDMA, both for Direct Sequence Spread Spectrum DSSS [18] (see Figure 4) and for Frequency Hopping Spread Spectrum, FHSS, in which all users may use all the spectrum available during all time, but each user is assigned a special pseudo-random code in order to differentiate itself and encrypt/decrypt its transmission (see Figure 5) [25].

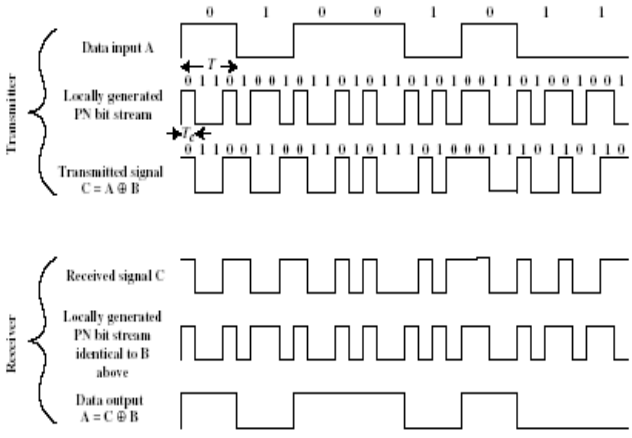

Figure 4. Direct Sequence SS (*Source*: [25])

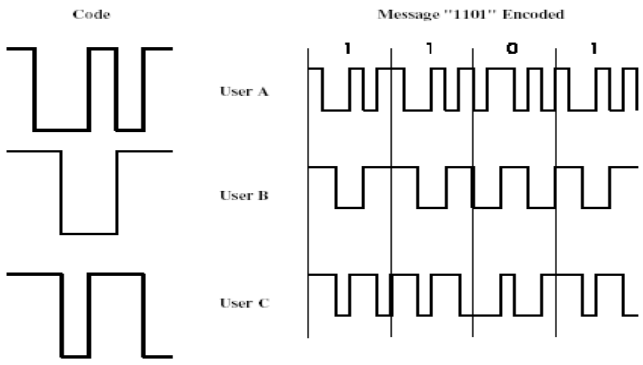

Figure 5. Distinct Message User Codes in DSSS (*Source*: [25])

6.2.4. Diversity and SDMA

Finally, the concept of spatial diversity is being employed more recently in parallel with SDMA access systems to combat multi-path fading of the wireless communications channel [24].

VII. 3G WIRELESS COMMUNICATIONS TECHNOLOGIES

7.1 Modulation, Coding, and Receiver Technology

3G Wireless communications technologies involve novel modulation, coding, processing and receiver design technologies. Following the functional decomposition of Figure 6 below, we list the different technologies employed in various building blocks of a Wireless Communication System. For example, there are different multiple channel access methods (FDMA, TDMA, CDMA-DSSS and FHSS, SDMA) and multi-user fixed (voice) and random (data) access methods (DSMA, BTMA, & dynamic ALOHA) used by mobile data services [2], the most important multiplex technologies (OFDM, COFDM, TDD, FDD).

Base-band pulse shaping is also employed in some cases prior to the use of 2G and 3G modulation technologies (FSK, GFSK, m-PSK, π/4DQPSK, GMSK, OQPSK [27], adaptive or reconfigurable modulation) [28], both linear and non-linear and single carrier and multi-carrier techniques. 3G FEC coding techniques (cyclic, BCH, Reed-Solomon codes, convolutional coding, Trellis Coded Modulation (TCM), Viterbi Decoders, interleavers, recursive codes, turbo coding, adaptive and Space-Time Coding, Block Coded Adaptive OFDM, and Fractal Coding [29] for multimedia compression). Multi-carrier CDMA is combined with OFDM techniques and there is a special No/Carrier modulation technique called UWB (Ultra-wideband radio) that employs modulation of extremely short pulses. All these 3G/B3G technologies will support Broadband Wireless Multi-user Communications, Ultra wideband Radio and Adaptive or Reconfigurable Software Radio [21,41].

7.2 Radio Channel Technologies

There are Narrowband and Broadband Radio Channels, and two categories of models for them: Time Channel Models [30], Space Channel Models and combined Space-Time Channel Models [31].

7.2.1 Time Channel Models

There is the Additive White Gaussian Noise model (AWGN), the discrete memory-less channels, the BSC channel, non-binary channels, time-varying Random Channels and Discrete Multi-path Channels[30].

7.2.2 Space Channel Models

Among these space channel models there are the Vector and Scalar Space models, and other first and second order statistic models which take into account angle spectrum concepts, and multi-path shape factors to account for spatial diversity of the multiple carriers in the channel.

7.2.3 Space-Time Channel Models

These are used to model wideband channels, multiple input multiple output or MIMO channels, with multiple antenna systems, and channel separation through multi-path [31].

7.3 Propagation mechanisms

Among the most common propagation mechanisms that can be encountered in a radio channel are Temporal Diversity, Spatial Diversity and Angular Diversity. Among the Temporal Diversity propagation mechanisms we have Multi-path, Fading (Random, Small Scale), Rain attenuation, Doppler Effects, Dispersion, and Interference.

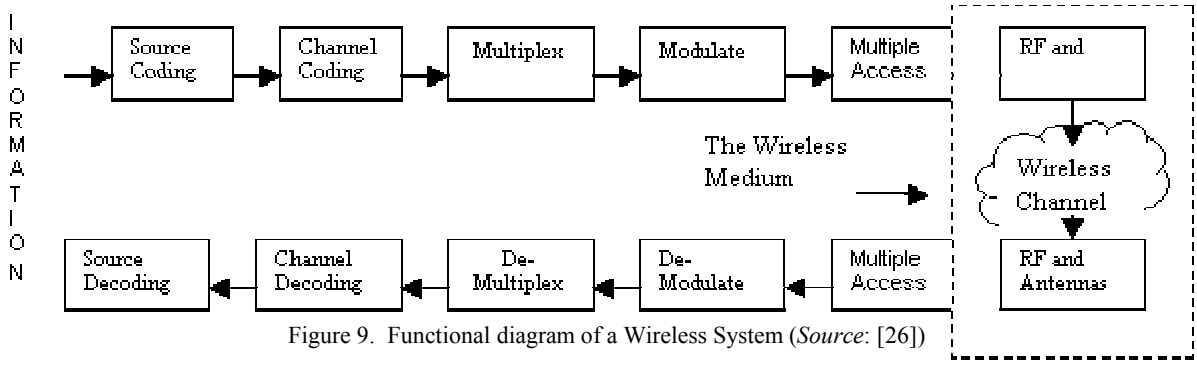

Figure 9. Functional diagram of a Wireless System (*Source*: [26])

Among the Spatial and Angular Diversity propagation (both co-channel and intra-channel) mechanisms, we have the beam-forming diversity of antennas, the angle spectrum and multi-path shape factors to take into account. A variety of earlier path loss models exist (Rayleigh, Rice, Nakagami) and newer path loss models for wideband channels which have to take into account the non-linearity of the wireless channel and the fact that there is not only Gaussian Noise being added, but also interference and other losses which interact in a non-linear manner in the performance of the channel. This implies that what was thought to be pessimistic models under the linear channel AWGN noise, tend to become optimistic, and there is the need to do measurement of real scenarios in order to model the channel.

Thus, different wireless propagation mode models are being sought for a more realistic modeling of the wireless channel, as a power-limited, space-varying, time-varying, frequency-varying channel which creates an open-ended design problem [31] to optimize the system in the presence of various types of noise.

VIII. B3G / 4G Mobile Communications Technologies

The world beyond 3G (B3G) is being worked on currently to develop 4G standards presumably by 2007 and onwards and deployed after 2010 [13]. Various groups are working on B3G and 4G such as the ITU-R, the Wireless World Research Forum (WWRF) and IEEE Project 802, but 4G research has two groups within the ITU: one working on high data rates up to 100Mb/s and another one working on Open Architectures to ensure "seamless inter-working" among technologies [13]. These research directions seem to gain support by three other concepts that will no doubt appear in B3G and 4G networks: Adaptive Networks, Wideband Channels and Multi-user all IP Networks [32] interoperable networks, even with LEOS, MEOS and GEO satellite networks. 4G Processing technologies include antenna array signal processing, and UWB (Ultra-Wideband Radio) for adaptive Ad-Hoc networks [33].

IX. 3G Wireless Networks Design

3G Wireless Network [25], [34], [35]. Design is often associated with fixed [36] or Mobile broadband or wideband [37] voice, data and multimedia WANs. Broadband local networks are associated with WLANs, and Indoor and short range wireless communications with WPANs. Wireless Network Design implies the Design of the Wireless Communication System Elements [38], the simulation [30] of the Wireless Network [34], and planning [39] activities such as the cellular network topology y planning, number of cells decision, signal-to-interference ratio calculations (SIR) to estimate coverage, traffic capacity, handoff strategies, security (cryptography, authentication and key generation algorithms) [40].

X. Conclusions

This paper has surveyed and organized the more important concepts and topics that a Wireless Communications engineer has to be conversant with in order to be able to understand and contribute to this exciting area. This paper hopes to serve as a study guide for the most important topics in the Area of Wireless Communications.

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