Optics and Lasers in Engineering 89 (2017) 95–108

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

New challenges in wireless and free space optical communications

A. Mansour [a,*], R. Mesleh [b], M. Abaza [c]

[a] Lab STIC - ENSTA Bretagne, 2 Rue François Verny, 29200 Brest, France
[b] Communication Engineering Department, German Jordanian University, Amman 11180, Jordan
[c] Electronics and Communications Engineering Department, Arab Academy for Science, Technology and Maritime Transport, Cairo, Egypt

ARTICLE INFO

Article history:
Received 26 January 2016
Received in revised form
11 March 2016
Accepted 25 March 2016
Available online 12 May 2016

Keywords:
Wireless Communication
Dynamic Transmission Channel
Cognitive Radio
Software Defined Radio
Spectrum sensing
Higher order statistics
Spatial diversity
Dynamic spectrum access
Electronic warfare
Millimeter wave communications
Free space optical communication systems

ABSTRACT

This manuscript presents a survey on new challenges in wireless communication systems and discusses recent approaches to address some recently raised problems by the wireless community. At first a historical background is briefly introduced. Challenges based on modern and real life applications are then described. Up to date research fields to solve limitations of existing systems and emerging new technologies are discussed. Theoretical and experimental results based on several research projects or studies are briefly provided. Essential, basic and many self references are cited. Future researcher axes are briefly introduced.

1. Historical facts and applications

The recent spread of cellular systems (smart sensors, mobile phones, base stations, satellites, surveillance devices, traffic radars, etc.) has increased the complexity of processing algorithms and pushed the existing technologies to their limits. Detailed analysis of the raised issues and/or deep discussion of any of the proposed solutions is nearly impossible in a single article. Nevertheless, the objectives of this paper are to shed light on the main applications, present recent research fields and summarize some of our obtained results in various research projects and studies.

Before discussing recent applications and the limitations of existing technologies, we would like to mention the dusk of wireless communication systems. At the beginning, there was a research study divided into 4 parts to discuss “the physical lines of force” published in 1861 by a Professor of the King's college in London. The author of this study was the imminent scientist J.C. Maxwell [1–4]. In his early study, Maxwell predicted the existence of “Electromagnetic Waves”. Few years later (1887), a German physicist, H. Hertz, proved the existence of such waves. After that, it took Marconi less than 10 years to invent the first radio transmission system in 1896 and to patent his idea one year later [5]. The first radiotelephone service was introduced in the US at the end of the 1940s [6]. However, the first standard of radio mobile was introduced in the s1970s of the last century.

In the first transmission system of Marconi, the considered antennas were bigger than the building of Marconi's laboratory and the electrical circuits of the transmitter occupied the whole room. However, engineers and researchers have been very creative in the invention of new applications, shrinking the electronic circuitry and improving and diversifying proposed services. Since the beginning of the last century, telecommunication societies have proposed a great number of commercial services. In the beginning, wireless transmission systems were related to huge applications such as radio and TV broadcasting, military radars, and maritime radars. Analog transmission systems were very popular till the beginning of the 1980s of last century. These technologies became very limited to handle all the needs of modern societies.

Actually, our every day life is full of applications related to wireless communications. The list of such applications and

* Corresponding author.
E-mail addresses: mansour@ieee.org (A. Mansour), raed.mesleh@ieee.org (R. Mesleh), mohamed.abaza@aast.edu (M. Abaza).
URLs: http://ali.mansour.free.fr (A. Mansour), http://www.gju.edu.jo (R. Mesleh), http://www.aast.edu (M. Abaza).

http://dx.doi.org/10.1016/j.optlaseng.2016.03.027

services are very long and it cannot be restricted to the following major applications of wireless communication systems: mobile phone, tablets, portable media player, radios and televisions, wireless remote devices, several communication protocols (such as: Wifi, Wimax, Zigbee, etc.), robotics, smart cars and smart roads [7], smart Grid [8], many biomedical devices use wireless technologies, satellites, etc. Radars are also used in various purposes such as: land radars for airplanes surveillance in civil or military goals, security road traffic, meteorology, ground Penetrating Radar, Astronomy,[1] Airborne Warning and Control System (AWACS),[2] etc.

2. New challenges in wireless communications

Using the standards for frequency allocation published by 3 different standard bodies (International Telecommunication Union (ITU) [6], European Conference of Postal and Telecommunications Administrations (CEPT) [12], Inter-American Telecommunication Commission (CITEL) [13]) and some information from NASA [14], the main applications with the allocated wavelengths and the frequencies of major electromagnetic waves (EM) are illustrated in Fig. 1.[3] The relationship between the wavelength of an EM with respect to its frequency is given by:

$$\lambda = \frac{C}{F} = \frac{3*10^8\ \text{m/s}}{F\,(\text{in Hz})}$$

Fig. 1 clearly shows that the spectrum is very congested and that there exists no room for new applications and services. We should also mention that Short Message Service (SMS) which is relatively a recent application for mobile phones has been generating benefits around 110 billions US$/year worldwide [15]. This fact proves that the communication markets is massive. According to the independent, a UK newspaper on Tuesday 7 October 2014, “There are officially more mobile devices than people in the world. The world is home to 7.2 billion gadgets, and they're multiplying five times faster than we are”. Besides, customers become more exigent. Communication industries try to cope with the increasing number of customers and their exigencies. The First Generation (1G) of a mobile phone has been introduced in the market between 1970 and 1984. 1 G could only handle basic voices and it was based on analog protocol, i.e. Frequency Division Multiple Access (FDMA). The speed of this standard was around 2.4 Kbps [6]. Almost a decade later, the 2nd Generation (2G) was introduced (1980–1999) to improve the coverage and the capacity. 2G considers two different standards: Time Division Multiple Access (TDMA)/Code Division Multiple Access (CDMA) and it reaches a transmission rate of 64 Kbps. At the beginning of the 1990s, the third generation (3G) was introduced to deal with voices and data (multimedia, text, the Internet, etc.). It was based on CDMA and had a bit rate of 2 Mbps. The fourth generation (4G) has been deployed since the beginning of this century and it is using an Internet Protocol (IP) and Long-Term Evolution (LTE) standard. 4G is mainly optimized for data that can reach around 100 Mbps. Actually, many standard bodies are developing the fifth Generation (5G). This generation should reach around 1 Gbps and it should be adapted to handle the Internet of Things (IOT). The IOT is a major challenge for our communications networks. In fact, IOT will allow the communication among devices, which will be massively deployed in [16]: smart cars, smart roads, smart cities, smart houses and buildings (in the context of homes and building automation), security and safety (surveillance, alarm, site networking), and industrial M2M communication. It is anticipated that in 2020, there will be around 50 Billion connections. According to Cisco [17], “Fifty billion things will connect to the Internet of Everything in just a few years. The value this could create for service providers by 2022 is US$1.7 trillion”. Fig. 2 presents the dilemma of the telecommunication industries, where the increasing of the customers' number will definitely impact the spectrum bands which are already congested.

3. Prosper research fields

To resolve the problems of wireless communications, researchers and engineers from all around the world are actively prospering new research fields and proposing new technologies. It is worth mentioning that the creation of new technologies can help solving some issues. Indeed, the broadcasting of digital terrestrial television (DTTV) instead of the old analog television one liberates some spectrum bands, called the “White Spaces”, as the DTTV consumes smaller bandwidths comparing to the ones required in the analog case. The technology progress is out of the scope of our manuscript and it will not be considered hereinafter. In this section, the major new axes of research related to wireless communication systems and networks are considered.

3.1. Smart and cognitive radios

Cognitive radios (CRs) can scan and analyze their environment and adapt their transmission/reception parameters to better convey and protect transmitted data [18,19]. CR can be mainly divided into two categories: smart individual radios and smart networks (largely considered as cognitive radios). A smart radio can dynamically be auto-programmed and configured. Smart networks optimize the total use of available physical resources among its members. Fig. 3 presents the three main functions of a smart radio. In the case of a cognitive radio, the main decision function can be made in the central unit while the scanning and the analysis procedures can be done in each individual unit (a transmission unit can be affected to a primary or a secondary user). In order to optimally share the physical resources, CR classifies the transmitters (the users) into two categories: primary and secondary users. A primary user (PU) is the user holding a license of a defined spectrum. He is allowed to use his bandwidth any time as far as he is respecting the cover area and the transmission power. As many primary users do not broadcast all the time, their protected bandwidths are not used optimally. Therefore, an opportunistic user (i.a. a secondary user (SU)) can use the best available bandwidth as far as his signal does not interfere with the signal of PU at any time. This process is discussed further in Section 3.4.

As CR should scan their environment and get adapted to it; they should have the capability to identify, classify and analyze signals in the context of non-data aided. In previous Communication Intelligence (COMINT) projects and research studies, several algorithms to estimate unknown parameters of intercepted signals were proposed. An intercepted signal can be detected using a spectrum analysis or an energy detector. However, this operation

[1] It is worth mentioning that the huge antenna on Earth belongs to the USA radio telescope, the Arecibo observatory in Puerto Rico, which is the world's largest single-aperture telescope (above 300 m). “It is used in three major areas of research: radio astronomy, atmospheric science, and radar astronomy.” [9]. We should also mention the new and great project of the Square Kilometer Area (SKA) [10].

[2] “The E3 look-down radar has a 360' view of the horizon, and at operating altitudes with a range of more than 320 km. The radar can detect and track air and sea targets simultaneously.” [11].

[3] Where 1 atto = 1 a = 10^{-18}, 1 femto = 1 f = 10^{-15}, 1 pico = 1 p = 10^{-12}, 1 Angstrom = 1 Å = 10^{-10} m, the diameter of an hydrogen atom is estimated to be 1 Å, 1 nano = 1 n = 10^{-9}, 1 micro = 1 μ = 1 u = 10^{-6}, 1 milli = 1 m = 10^{-3}, 1 centi = 1 c = 10^{-2}, 1 Kilo = 1 K = 10^{3}, 1 Mega = 1 M = 10^{6}, 1 Giga = 1 G = 10^{9}, 1 Tera = 1 T = 10^{12}, 1 Peta = 1 P = 10^{15}, 1 Exa = 1 E = 10^{18}, 1 Zetta = 1 Z = 10^{21}, 1 Yotta = 1 Y = 10^{24}.