

THE CODE DIVISION MULTIPLE ACCESS – FROM “COMPLICATED” TO THE ACTUAL MOBILE COMMUNICATIONS STANDARDS AND BEYOND

Prof. Eng. Ph.D. Victor GREU



Abstract

The paper approaches one of the most important technologies of the modern communications – the Code Division Multiple Acces (CDMA), which has a huge influence on the actual mobile communications networks (3G, 4G) and beyond.

The paper presents CDMA from a dual point of view, as a powerful technology for the most dynamic communications networks, cellphone broadband mobile communications, but on the other hand revealing that CDMA represents also one of the information and communications technologies (ICT) that could influence people and their ways of thinking, as a model.

Some interesting aspects covered by the paper present important moments and contributions in the spectacular evolution of CDMA, in USA, Romania and generally manifest in the World, as CDMA is an inherent feature of the spread-spectrum systems (SSS) of communications (first and long time used only for secure military communications) and both CDMA and SSS were very skeptical perceived by the civilian specialists and the industry, because they were long time considered „too complicated” for commercial use.

One of the paper’s points stress the deep significance of the CDMA/SSS evolution, as a long fight against all the challenges, a process where the knowledge, the innovation and the passion were the main ingredients of the final succes – a huge achievement for ICT and the information society (IS).

One the same line, the paper’s conclusions refer to the power of CDMA to leverage the mankind activity, by technological concrete consequences and also as a model to manage the resources - from time and electromagnetic spectrum to anything people must share on Earth.

Keywords: *Code Division Multiple Acces (CDMA), communications and information technologies, information society, cellphone communications, spread-spectrum communications.*

JEL Classification: *L63, L86, M15, O13, O33*

1. The Code Division Multiple Acces (CDMA) shorted but fascinating story

The communications technologies (CT), as a prominent part of the information and communications technologies (ICT), is a major factor of the mankind progress in the last 120 years and for sure for the further evolution of the human society as „information society” (IS) and then for the transformation of IS towards the future „knowledge based society” (KBS) [6], [8].

It is interesting to observe that the „switching centre” from the infancy of the telephony could be considered the first electric computer, leading the development of CT to the information technology (IT).

Today we asist at the apogee of CT and IT convergence, as the information and communications technologies (ICT), a phenomenon which dramatically influenced the world in the last decades and is generating the process of IS development.

Inside the ICT, starting with the '90s, the mobile communications's amazing development represent perhaps the most important process, as they became, by the broadband spectacular „explosion”, the main support of the revolutionary ICT products and services.

The above premises clearly show why the mobile communications (MC) is a subject of the highest interest for the ICT and IS.

On the other hand, the exponential development of ICT in the last decades is naturally supported by the complex achievements in technology, including software, but they also relies on more and more sophisticated theoretical basics, as digital modulations, codes and so on.

This way we have just arrived at the emerging questions: What CDMA is? / Why CDMA?

As a matter of fact, when we have mentioned digital modulations and codes, we half answered at „Why CDMA?”.

Simply, CDMA could be considered a combination of codes and digital modulations theories, intended for optimazing the multiple acces capacity of the wireless communications networks, especially from the point of view of frequency spectrum use and the interference resistance.

The reality is that CDMA is far to be simple, as its „complicated” features were recognized from the beginnings and long after [1].

Of course, the objective of this paper does not include a detailed presentation of CDMA, but we intend to reveal its actual and future importance along with some remarcable aspects of its evolutions, in order to extract the premises that CDMA offers, to ICT and even to IS, to be an useful paradigm which could generate influence beyond its natural technological applications - a model to approach the generic „networks” either inside of ICT and generally in IS.

Coming back to the „interference resistance” feature we may find the theoretical origins of CDMA, inside a more complex concept named „spread spectrum systems” (SSS), which was founded by Claude Shannon in 1945.

In 1945 Shannon wrote a paper, “A Mathematical Theory of Cryptography”, but never published because it was stamped SECRET. A „cleared” version was still published in 1949, as „Communication theory of secrecy systems”.

Again simply, we may say that Shannon theoretical model (equation) postulated SSS as a wireless communications system which could provide a given information transmission capacity, even in a very hostile environment (a signal/noise ratio much less than unit), if a corresponding frequency bandwidth (very large versus the information bandwidth) is used for transmission.

For security reasons, the large frequency bandwidth had to be obtained by „spreading” the narrow bandwidth of information, using codes and modulations which had to be known only by the transmitter and the intended receiver and this way, the last, in synchronism with the transmitter, could extract the information by correlation.

Those codes became the „heart” and „signature” of CDMA, as they could differentiate the users and the networks, allowing them to work in the same frequency band without interfering (multiple access) and „spreading” (rejecting) in the same time, all other (non-synchronized) signals.

Now it is clear why the word „complicated” was associated with CDMA and SSS.

Such a principle (SSS) and goal was surely first intended and used only for military purposes (for example in strategic/priority applications, as military GPS, JTIDS/AWACS communications, mobile SINCGARS frequency hopping radios), but later, when the technological progress allowed it (in the late '80s), the civilian/commercial applications of SSS became possible, necessary and efficacy. Notice that SSS were initially used only for communications and soon for radar, but later extended to satellite (like GPS), navigation etc.

The point is that the SSS's complicated concept, which was further developed long after Shannon's theory, included, as a native feature, the CDMA!

Perhaps, for this paper goal, it will be more relevant and clear, to point some interesting, but not necessary technical, technological or scientific, moments and aspects of the CDMA/SSS evolutions, as it follows.

This year, Irwin M. Jacobs received 2013 IEEE Medal of Honor for „leadership and fundamental contributions to digital communications and wireless technology”, as CDMA powers all 3G networks and is expanding its basics to 4G.

It is considered that Irwin M. Jacobs launched „a wireless revolution” [1].

Before leaving Massachusetts Institute of Technology (MIT), graduated by Jacobs after being a life-guard, a photo developer, a lumberjack and student at School of Hotel Administration [1], (Irwin) „Jacobs and fellow faculty member John M. Wozencraft had written a textbook on communications theory, *Principles of Communication Engineering*, first published in 1965 and still used”.

In 1966, after he earned a doctorate at MIT, he left for helping launch an engineering school in California, as professor at University of California, where he started a consulting company (Linkabit Corp), together with professors Andrew Viterbi and Leonard Kleinrock.

In 1985, Jacobs joined with six others, including Viterbi, he started Qualcomm, a company which later had developed commercial CDMA and today is a leader in the world of communications and generally ICT.

One of the first contracts of Qualcomm was with Hughes, to develop a mobile satellite system, where Hughes intended to use conventional spectrum-sharing techniques.

In one of those days, in a car [1], in a pause between conversations with Andrew Viterbi and Klein Gilhousen, Irwin Jacobs thought that, inspite of the fact that CDMA were considered by other specialists „too complicated” for being used outside military applications (for commercial use), this technique could „squeeze” other users in the pauses between conversations of some users, as a multiple access in the same band.

That idea was the origin of the later epocal extention and evolution of CDMA in civilian applications, i.e. for cellular mobile communications.

In a similar way, keeping the scale, in 1979, when I have received the theme of the graduation paper at the Military Technical Academy (Bucharest) on „SSS communications”, everybody considered as „science fiction” the possibility to have wireless communications in the presence of a jamming with power of hundred times the useful signal power.

Such opinions have persisted in 1981 when I have presented the first article on SSS at Politehnica University of Bucharest [11] and almost up to the publishing of the first books on SSS in Romania [5], [2].

It is worth to mention that SSS literature began to be public in a progressive manner, after 1982 when USA started their programme SINCGARS to develop tactical frequency hopping radios in the period 1982-1994 (aiming about 400 000 units in 1994).

In this context, the participation in 1992 at the first demonstrative exercise with tactical frequency hopping radios (Tadiran/SINCGARS- Bacau-Romania) and in 1995 at the Romanian Army’s auction for tactical frequency hopping radios (won by Racal-JAGUAR) and the SSS doctoral thesis in 1995 [7gv thesis], represent moments of the evolution of SSS in Romania and in the same time results of *what people’s knowledge and passion can do*.

Knowledge and passion were the ingredients Irwin Jacobs (and Andrew Viterbi – the recipient of 2010 IEEE Medal of Honor) used to transform, after 1985, the CDMA extension idea into the actual mobile communications standards basics. That does not mean it was an easy way!

Between 1985 and 1989, Jacobs and his Qualcomm team, after showing the main advantages of CDMA for cellphones (higher number of users, better spectrum use, jam proofing communications) studied and solved „one of the biggest complexities” of CDMA: controlling the power of signals sent from the cellphone to the cell tower[1].

In 1989, when the first generation (G1) of mobile communications (MC) was in use as analog technology, the principal producers decided to choose TDMA (time division multiple access) for the next generation of MC (G2), a digital technology, because they considered CDMA „too complicated” for G2.

Despite of these opinions, Irwin Jacobs and Qualcomm continued the research and in november 1989 invited 100 producers or operators of cellphone systems at a CDMA demonstration, in San Diego.

The demo was very dramatic: „if that demo had failed, we probably would have been died”, as Jacobs recalls [1].

As a matter of fact and strange coincidence, the two CDMA base stations had well operated, but they had used for synchronization (one of the most complicated problems of SSS and CDMA) the signals from then-nascent GPS (Global Positioning System) – a constellation of 24 satellites which today is the „natural” support for a huge diversity of mankind activities.

For Jacobs’s desperation, the demo was blocked for 45 minutes, because in that period one of the GPS was itself out of synchronization. Notice GPS was using SSS/CDMA!

Finally the demo was an impressing success, but the CDMA way to industry was still long.

In 1991, Jacobs and Qualcomm had demonstrated CDMA for cellphone communications in New York, but the skepticism of wireless carriers executives still persisted.

Very interesting is that, **at 1991 demo**, a Stanford professor „told people that CDMA violated the laws of physics” and The Wall Street Journal claimed in September 1996 that

„Jacobs hype was causing carriers and cellphones manufacturers to throw away billions of dollars”[1].

As a strange coincidence (but *great for Romania*) is the fact that **10 years before**, when I have presented in 1981 my first paper on SSS, at Politehnica University of Bucharest

[11], a very well known communications professor, who wrote [12], said: „what this young guy has presented it's impossible to work”.

On the other hand, Jacobs and Qualcomm continued and in July 1993, the Telecommunications Industry Association approved CDMA as standard. The first commercial CDMA network became operational in 1995 (Hong Kong) and Qualcomm is today a 115 billion USD company [1].

The rest, achieving G3 and up to today in G4, is the long (not shorted) story of CDMA in World's mobile broadband communications.

2. How CDMA reveals one more time the ICT potential to leverage IS development and people's knowledge and innovation capacity

One of the fascinating mechanisms of ICT exponential development is the power of its innovations to multiply their effects not only in the technological world, but also in the human society they build as IS, by a diversity of consequences, mainly linked with the people's minds.

In the reality, the IS development, even if it is based on ICT growing, would not be possible if ICT would not have such a complex and dramatic mutual dependence with the mankind creation capacity.

If we try to find the beginning of this „circle”, we surely must admit that always the man is first, i.e. understand how important the knowledge, the innovation and the human passion are, for the achievement of such huge and complicated things, as CDMA/SSS is.

Recalling the above story, it is clear not only What is CDMA? but also Why CDMA?, as CDMA proved to be, like IP (Internet Protocol), a “must” of ICT progress.

An amazing observation at this moment is that despite the CDMA/SSS future power, at the beginning, a large community of specialists considered it from “impossible” to “too complicated”.

Now it is easy to get the paper point: such great mankind achievements could be obtained only by highly refined knowledge, innovation capacity, a lot of passion and ... hard working.

Of course, CDMA is not the single example, but is one of the most recent and relevant, in science and technology history. Another example (name) could be enough: Einstein.

On the other hand we have to also stress how important is that ICT is leveraging these people's skills, especially the innovation capacity and the processes of refining knowledge [3], [10].

Here we would like to reveal the particular ways CDMA, as a prominent concept of actual ICT, could help people's creation processes.

As we already presented in the Network Centric and Cloud cases [9], CDMA is also a model that could influence IS beyond the obvious ways of the ICT technological implications, even if the CDMA influence were not in the same ways and dimensions.

The essential observation could be extracted just from the Irwin Jacobs's initial idea: we can optimize a process by reusing the pauses, i.e. the time.

One could say: Nothing new under the sun! And yes, he would be right.

We also have mentioned [9] that one of the ICT essential contributions to the people's education and to IS given by the products and services which enable the people to reuse the time and generally to optimize the use of time with an amazing efficiency.

If we would try again to simply express the „too complicated” CDMA, we have to observe that the novelty CDMA brings, versus the conventional multiple access techniques

(TDMA- time division multiple access; FDMA=frequency division multiple access) consists of optimizing both time and frequency, in a sophisticated manner: by assigning to users and networks special codes, which may be simpler (shorter and easy generated) or very complicated (longer, if necessary highly and multi-criteria elaborated), depending of application's desired performances.

As an other strange coincidence, we achieved [7] by extending Gold codes generating techniques and proposing a new similar class of codes for CDMA/SSS [4]. And how? By refining mathematical knowledge (Galois Extended Fields), work, passion and ... Personal Computers.

Coming back to people, ***CDMA could teach us to optimize time and other resources*** (not only frequency spectrum), by refining (coding=linking in new ways) the knowledge, i.e. innovating the ways we used to think, we used to do anything, we used to work, we used to consume, we used to learn, we used to imagine and so on.

In all the above examples, using the CDMA's model, the people could learn, without restricting their rights, that in the more and more „complicated” life on Earth, we have to refine our knowledge using the latest information, we have to innovate new ways to improve or at least to preserve all the Earth and mankind resources.

We have also to adapt and face the new challenges of life, including the „side effects” of the technological progress, using the CDMA/SSS models, which „compute” and provide any „slice” of ***all the resources*** for every user and network, in a precise and negotiated order, avoiding interference and conflicts.

Perhaps the simplest form to concentrate the paper's essence is to emphasize the power of CDMA to leverage the mankind activity, by technological concrete consequences and also as a model to manage the resources - from time and electromagnetic spectrum to anything people must share on Earth.

A subsequent lesson people could learn from CDMA is to better and wiser live with the neighbours and environment, reducing the „mutual interference” and being more tolerant on a rational (coded=calculated/rational) basis.

The „secure” feature of CDMA/SSS could help us to respect privacy and personal information, such idea being very actual as social networks already reveal their risks on privacy and overdoing.

In the same field of Internet and beyond (in IS) we may see the danger of governments tendencies to interfere with the private life and information, without speaking of similar international political actions, state cyber-attacks etc.

Finally we may come back with an optimistic observation: ***against all of these „attacks”, CDMA/SSS could defend and support us in concrete ways, based on standards which include CDMA/SSS, as IEEE 802.xx family (which includes WiFi, Bluetooth, WiMax) and the universal cellphone networks 3G and 4G and...beyond.***

3. Conclusions

CDMA and SSS are prominent achievements of ICT, which are leading the development of modern communications, including their most dynamic branch, the broadband mobile communications as universal 3G and 4G cellphone networks.

CDMA, as an inherent feature of SSS, first used for secure military wireless communications and soon for radar, but later extended to satellite (like GPS), navigation etc., has been proposed after 1985 for commercial cellphone networks by Irwin Jacobs (and his Qualcomm team), but despite of the fact that most of the specialists considered CDMA „too complicated” at that moment, their knowledge and determination led to the actual huge applications of CDMA.

This paper's space only partial could express the power of CDMA to leverage the mankind activity, by technological concrete consequences and also as a model to manage all resources - from time and electromagnetic spectrum to anything people must share on Earth.

More than these, among other ICT models (like Network Centric and Cloud), CDMA/SSS could leverage people's creation capacity and improve their efficiency when using limited resources in the IS, being in the same time an example of what people's knowledge, innovation and passion can do, when facing the life challenges either in Romania, USA or anywhere on Earth and ... beyond.

REFERENCES

- [1] Tekla S. Perry, *Captain Cellular*, IEEE Spectrum, May 2013.
- [2] Victor P. Greu, *Jamming and Interference resistant radio communications*, The Military Printing House, Bucharest, 1992 (in Romanian language).
- [3] Robert W. Lucky, *Other people's knowledge*, IEEE Spectrum, January 2013.
- [4] Victor P. Greu, Bogdan Vasilescu, *Basic method for generating "quasi-orthogonal" spread-spectrum signal formats*, Proceedings of the International Conference "ECCTD'97(European Conference on Circuits Theory and Design)", Budapest-Hungary, 1997.
- [5] Victor Greu, Alexandru Serbanescu, *Methods, Techniques and new Technologies in Communications-Vol.IV (Wideband Radio Communications Systems)*, The Military Technical Academy Printing House, Bucharest, 1989 (in Romanian language).
- [6] Abdulaziz S. Almazyad and Farooqui N.K., *Towards Knowledge Based Society*, Proceedings of the World Congress on Engineering and Computer Science, 2009, Vol II, WCECS 2009, October 20-22, 2009, San Francisco, USA.
- [7] Victor P. Greu, *Methods to realize the spread-spectrum communications systems (Doctoral Thesis)*, The Military Technical Academy, Bucharest, 1995 (in Romanian language).
- [8] *** *Towards a knowledge based Europe The European Union and the information society*, European Commission Directorate General Press and Communication, October 2002.
- [9] Victor Greu, *The Network Centric And Cloud - A New Paradigm For The Optimization Of The Technical And Human Information Systems*, Romanian Distribution Committee Magazine, Volume 2, Issue 2, Year 2011.
- [10] Carlos Baladron, Javier M.Aguilar, Belen Carro, Lorena Calavia, Alejandro Cadenas, Antonio Sanchez-Esguevillas, *Framework for intelligent service adaptation to user's context in next generation networks*, IEEE Communications Magazine, mar.2012.
- [11] Victor Greu, *Interference Stable Spread-Spectrum Information Transmission Techniques*, Presented at The Jubilee Conference „100 years of engineering higher education in Romania”, Politehnica University of Bucharest, 1981 (in Romanian language).
- [12] Mugur Savescu, *Radiorelays and spatial radio communications, Pedagogical and didactic Printing Hous, Bucharest, 1976 (in Romanian language).*